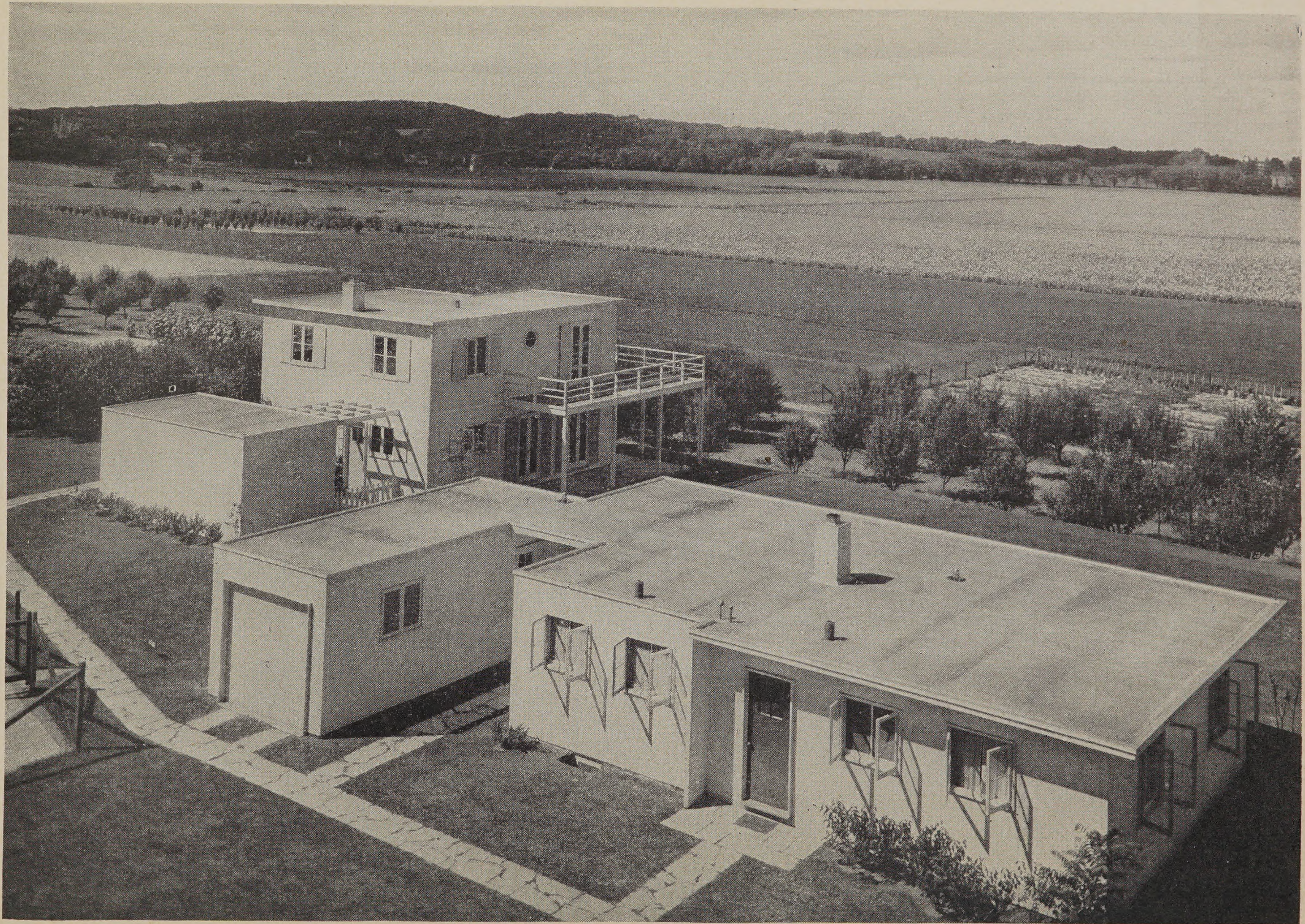
MANUAL ON WOOD CONSTRUCTION FOR PREFABRICATED HOUSES

OFFICE OF THE HOUSING EXPEDITER

AND

HOUSING AND HOME FINANCE AGENCY



Prefabricated houses built by the Forest Products Laboratory in 1937 as part of its research in developing the stressed-cover principle with wood and plywood for prefabricated housing.

MANUAL ON

WOOD CONSTRUCTION

FOR

PREFABRICATED

HOUSES

WASHINGTON, D. C., DECEMBER 1947

PREPARED BY

THE FOREST PRODUCTS LABORATORY

FOREST SERVICE

U. S. DEPARTMENT OF AGRICULTURE

IN COLLABORATION WITH THE

TECHNICAL STAFF OF THE

HOUSING AND HOME FINANCE AGENCY

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FOREWORD

Construction techniques for wood-prefabricated houses have been developing in the United States for several decades. Some of the technical know-how acquired in this development has been made generally available, but most of it to date has remained in the factory and laboratory. The present demand for low-cost housing points up the need to accelerate the development of prefabrication of buildings, sections and parts as an aid to meeting our housing needs. Since wood and wood products constitute such an important part of our building materials, a comprehensive guide and reference work on construction techniques for wood prefabrication is vitally important. This manual, which covers a wide range of basic information, assembles much that is already known, but it also makes new contributions to the subject and presents the results of extensive tests and studies in wood handling and processing by the Forest Products Laboratory. It should be helpful to house designers, prefabricators, builders, contractors, engineers, housing officials, and others who are interested in planning and building wood-prefabricated houses.

RAYMOND M. FOLEY,
Administrator, Housing and Home Finance Agency.

ACKNOWLEDGMENTS

This manual has been prepared by the Forest Products Laboratory, Forest Service, U. S. Department of Agriculture, Madison, Wis., in collaboration with the Technical staff of the Housing and Home Finance Agency, Washington, D. C. (formerly the Technical Office for the National Housing Agency and the Office of the Housing Expediter). It is based chiefly upon the accumulation of information that has resulted from engineering studies and allied investigations conducted by the Forest Products Laboratory during the past 36 years, supplemented by information obtained in a recent survey of current fabrication methods in United States prefabrication plants. The manual has been compiled under the supervision of R. P. A. Johnson and F. A. Strenge of the Forest Products Laboratory with the assistance of William V. Reed, former Director, Technical Office, NHA; Leonard G. Haeger, Director, and the Technical staff of the Housing and Home Finance Agency, which succeeded the NHA, pursuant to Reorganization Plan No. 3, effective July 27, 1947. Others of the Forest Products Laboratory staff who have materially contributed include R. F. Luxford, technical review; R. F. Blomquist, H. D. Bruce, M. E. Dunlap, H. W. Eickner, H. O. Fleischer, T. J. Martin, and M. L. Selbo, glues, gluing methods, and plywood; A. D. Freas, engineering and strength of materials; E. M. Davis, grading of lumber and machining of wood; L. V. Teesdale, insulation, vapor barriers, and ventilation; B. G. Heebink and E. Panek, repair methods; F. L. Browne, paints and finishing; G. C. McNaughton, fireproofing; O. C. Heyer, construction methods; P. K. Baird, R. J. Seidl, and A. J. Stamm, new products; J. O. Blew, preservatives and preservative processes; W. J. Baker, D. Brouse, A. Koehler, and C. V. Sweet, review.

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INTRODUCTION

1.0. PURPOSE AND SCOPE.—This manual has been prepared to assist prefabricators in the more efficient utilization of lumber, plywood, and related materials, so that production may be stimulated, technical problems overcome, and more, better, and more economical houses produced. Its purpose is to facilitate production of durable, permanent housing, and all considerations of design, materials, and fabrication methods are directed toward that objective.

The manual provides a basic source of scientific and engineering information about wood and wood-base materials needed to expand the Nation's facilities for the production of adequate, safe, and economical housing through the medium of factory fabrication. Various methods of prefabrication are described, both to facilitate the application of this information and to present to the house prefabrication industry an analytical review of current processes and techniques. Results of a survey of prefabrication plants in the East, Middle West, and Pacific Coast by staff members of the Forest Products Laboratory have been utilized extensively in the planning and preparation of this manual.

While this manual has been prepared specifically for use by prefabricators, much of the information contained herein is applicable to all types of housing, whether factory or site fabricated. The general information presented about properties of wood, plywood, and other materials, as well as that on lumber grading, preservative treatment, seasoning, storage, painting, insulation, glues, and fastenings, will find application regardless of the type of construction employed. The design and use recommendations given are, however, specifically intended for prefabrication. If such information is to be adapted for use in other construction systems, the builder is cautioned to make certain that reasonably comparable conditions of use exist.

1.1. PREFABRICATION.

1.10. Definition. — Commercial Standard CS-125-45, issued by the National Bureau of Standards, defines prefabrication thus: "A prefabricated home is one having floors, walls, ceiling, or roof composed of sections, or panels, of varying sizes which have been fabricated prior to erection on the building foundation. This is in contrast to the conventionally built home which is constructed piece by piece on the site."

This definition is necessarily general. It implies, however, that certain construction methods, such as precutting of joists, studs, and other framing members for assembly on the site, do not constitute prefabrication. Likewise, the incorporation in conventionally built houses of ready-built doors, windows, staircases, and millwork of various kinds does not constitute prefabrication. Such factory-built parts of houses, while representing prefabrication in themselves, are not primary structural parts. With or without them, the conventionally built house is still erected in terms of individual studs, joists, rafters, sheathing, floor and siding boards, and other parts, cut, nailed, and finished on the site.

1.11. General.—Basically, there is nothing new in the concept of factory assembly of house parts in panel or sectional form, ready for quick assembly at the site with a minimum of cutting, fitting, and other operations that can be done faster and cheaper in the factory. Such prefabrication dates back many years. Its primary objective was to place as much as possible of the building operation in a factory and away from the vagaries of weather conditions. An early form of prefabrication consisted essentially of nailing conventional framing, sheathing, and siding together in the shop and shipping sections to the building site. Advantages of such prefabrication, other than the avoidance of delays due to weather, included economies possible through the use of jigs, power cutting tools, and other equipment, and

the elimination of much waste of material. Erection at the site was speeded considerably. More or less off-setting these advantages were the added shipping costs incurred in shipment of cumbersome panels or sections instead of bulk lumber, nails, and other raw materials.

In general, the growing complexity of housing during the past half century has added greatly to the cost of shelter. In an effort to keep costs within the limits of the average family's purse, builders have sought and tried various ways of cutting costs. Prefabrication, with its promise of savings through use of factory techniques that have proven successful in other fields of consumer goods production, has been turned to as one answer to this demand for lower housing costs.

In many cases, the savings possible by prefabrication have been enhanced by substituting modern materials and engineering methods for the custom and tradition that dictate the sizes of framing members and coverings used in conventional houses. The theory is sound. Tests at the Forest Products Laboratory and elsewhere have shown that house components can be fabricated that are more than adequate for the loads to which the ordinary house may be subjected, yet use much less material than goes into the conventional house. The use of framing members of smaller cross section and thinner covering materials is made possible by the fuller utilization of the inherent strength of the materials. Truly efficient joints between the covering materials and the framing members, rather than the relatively inefficient joints provided by nails, are furnished by adequate glue joints and permit the covering materials to supplement the strength of the framing members rather than to serve simply as a covering.

Such construction has become more feasible in recent years with the development of modern moisture- and decay-resistant glues for the manufacture of plywood and the assembly of parts. These adhesives are suitable for exterior use and their utility has been rigorously tested by wartime experience in aircraft, ships, and many other forms of outdoor construction. These glues are chiefly of the synthetic-resin type. In housing, their application has led to the improvement of stressed-cover construction by providing more durable glue joints.

Stressed-cover construction in its present state of development has been applied chiefly in the fabrication of 4- by 8-foot panels. There appears to be no valid reason, other than convenience in design, why manufacturers should not adopt other sizes; a few, in fact, are already doing so. Others, through the adaptation of gluing equipment, are constructing full room-size stressed-cover wall panels.

The advantages of stressed-cover construction go beyond the saving in materials made possible through the use of smaller sizes of framing members and lesser thicknesses of covers. A lighter panel that is easier to handle in the factory, cheaper to ship, and more readily handled at the site is thus made. While date on production costs are still too meager to permit conclusive comparison with other construction methods, both factory and site, the system is recognizedly more adaptable to fabrication with machines than are the more conventional systems.

Some builders are employing designs which call for factory assembly of complete house sections which require little more than bolting together and anchoring to the foundation at the site. Others have devised types of arch and truss construction that employ various wall and roof panel materials, including those of sandwich construction. Doubtless, other materials and methods will be tried.

Whatever materials and designs are selected, the prefabricator must make his products—house parts—conform to available production facilities. Here, too, there is a wide-open field. Nevertheless, prefabricated houses must be designed with an intelligent understanding of the limitations of factory production. The component parts of the house must be readily fabricated within the limits of available jigs, assembly tables, power tools, and conveyor systems; they must be of such size, shape, strength, and weight as to facilitate handling, storage, shipping, and assembly. Parts design must take into consideration such factors as the flow of materials and subassemblies through the plant, the limitations of materials and machinery as to sizes and tolerances, and the various shaping, fitting, and assembly steps necessary to produce the final part. In short, the designer as a rule must keep within the limits of available production facilities.

Nor does good design end with such considerations. House parts, no matter how strong, how well adapted to mass production, or how superior in any other single respect, are not the end product of prefabrication. The final test of their value is how well they will function as parts of a complete house. In short, they must be designed to permit ready assembly into sturdy walls, floors, and roofs that can in turn be tied securely together and anchored to foundations. Only as the parts contribute to the structural soundness and durability of the finished house in all respects—not alone strength, but resistance to heat, cold, fire, decay, moisture, wear and tear, and similar hazards of use and exposure—can their permanent value be judged. On the skill with which the prefabricator blends all these essential ingredients of good housing into his final product rests his ultimate success.

1.2. PATENTS.—Few basic patents covering methods of prefabricated house construction have been issued by the United States Patent Office. Patent No. 2,147,575 was issued jointly February 28, 1939, to George W. Trayer and the late John A. Newlin, both then of the Forest Products Laboratory staff, and covers the application of the stressed-cover principle to a modular system of prefabricated housing. This is the basic patent issued in connection with stressed-cover house construction and, since the inventors were both employees of the Federal Government, has been dedicated by them to the free use of the public in the territory of the United States.

Various prefabricated house manufacturers have employed this basic system of stressed-cover prefabrication with plywood and other covering materials glued to wood frameworks, and various modifications of the original Forest Products Laboratory mullion method of joining wall panels have been evolved. One such variation has been covered in patent No. 2,218,465, issued October 15, 1940, by the United States Patent Office to Foster Gunnison. The patent covers a beveled spline set in grooved studs of adjoining panels, with the spline bevels at an angle other than that of the stud groove bevels. The patent also covers a method of bolting panels together.

A method of house prefabrication employing sectionalized walls, floors, and ceilings in conjunction with roof trusses is covered in patent No. 2,365,579, issued December 19, 1944, to Walter J. Mulligan, San Mateo, California.

Patent No. 2,034,265, issued March 17, 1936, to Robert W. McLaughlin, Jr., New York, N. Y., covers a method of prefabricated house construction employing hollow metallic stud assemblies and other features.

With the exception of the stressed-cover system developed by the Forest Products Laboratory, the construction features covered by the above patents are not described in detail in this manual. It is not known whether any of the methods of fabrication described and illustrated are covered by United States patent at the time of this writing; no thorough patent search has been made. Accordingly, this publication cannot be held to give any protection against action for infringement.

1.3. ILLUSTRATIONS AND TRADE NAMES.—The use of detail drawings and other illustrations in this manual to show current construction practices does not constitute an endorsement by any Government agency of the methods and practices shown. Likewise, the mention of any trade name or proprietary product does not imply such endorsement.

BASIC INFORMATION ON WOOD AS A HOUSING MATERIAL

2.0. GENERAL.—Wood remains a dominant material in house construction because it combines various properties essential in such construction. Among the most important are its strength, weight, ease of working and fastening, ability to hold fastenings, insulating properties, and stability (*2-1*).[1] While different kinds of wood possess these properties in varying degree, in general the common construction species and grades are used because of these characteristics. It is, in fact, the combination, rather than any single property, that makes wood a premier construction material. Since species vary in these properties, a given species is utilized in the parts of the house for which its particular combination of properties makes it best suited.

Basically, it is the structure and chemical composition of the wood itself that account for its unique combination of properties. Wood consists mainly of hollow fibers, the walls of which are composed of cellulose and lignin, the latter acting also as a cementing agent that binds them together. This lignin bond is so strong that breakage under stress usually occurs within the fiber walls rather than in the lignin bond between the fibers.

Unlike metals, which have generally uniform strength in all directions, wood has not, for instance, the same strength across the grain as parallel to the grain; its tensile strength may vary as much as 40 to 1, its crushing strength 7 to 1, and its modulus of elasticity 150 to 1 along and across the grain. Not only do different species of wood differ in their properties, but trees of the same species and even parts of the same tree may vary, depending on the growth conditions prevailing when the wood was formed.

Wood is a hygroscopic material; that is, it takes on or gives off moisture until the amount of moisture it contains balances with that of the surrounding medium. Like many other hygroscopic materials, it shrinks as it loses moisture and swells as it absorbs moisture.

Plywood is made up by gluing plies or sheets of veneer together, usually so that the grain of any one ply is at right angles to the grain of the adjacent ply or plies. The redistribution of material that results makes plywood much more uniform than solid wood as to strength and shrinkage. Synthetic-resin glues of the phenolic type contribute the water resistance necessary to make the joints in plywood durable for exterior use in housing.

The great water resistance of these phenolic glues is also utilized in the lamination of timbers for beams, posts, rafters, and other heavy framing members. In laminated wood, the grain of each layer, or lamination, runs in approximately the same direction as that of all others. Its principal advantages are that it permits the creation of large timbers from relatively small, thin pieces and, by careful selection and positioning of material, makes possible the manufacture of timbers free of strength-reducing defects occurring in the tree or due to seasoning. Laminating has the added advantage that, while the thin laminations are being glued together, they can also be bent to desired curvatures, as for arches.

2.1. STRUCTURE AND GROWTH

2.10. Bark, Wood, and Pith.—A cross section of a tree trunk shows certain well-defined features from the outside to the center: (1) the bark; (2) a light-colored layer next to the bark, called sapwood; and (3) an inner zone, usually darker than the sapwood, called heartwood. In the structural center of the log is a very small, soft core known as the pith.

2.11. Cellular Structure.—Wood is composed of cells for the most part tightly grown together. Each year new cells are produced on the outer side of the sapwood by a thin layer of cells, called the cambium, located between the bark and the sapwood. Wood cells vary considerably in size and shape within a piece of

[1] Italic numbers in parentheses refer to references cited at the end of each chapter.

wood and in different species. The principal kinds of cells and their usefulness in identifying wood species are discussed in section 2.14.

2.12. Springwood and Summerwood.—A cross section of a log grown in a temperate climate shows well-defined concentric layers of wood. These layers as a rule correspond closely to yearly increments of growth and for that reason are called annual rings. Many tropical timbers, however, show no well-defined annual rings because they grow more or less continuously throughout the year.

Springwood is the wood formed on the inner side of the annual ring during the early part of each growing season. It is usually more porous, softer, weaker, and, especially in the conifers, lighter in color than the summerwood, which is formed in the outer part of the annual ring during the latter part of the growing season. In most softwoods and some hardwoods, as, for example, oak and ash, the summerwood is considerably denser than the springwood; in others, such as white pine and beech, the difference is much less pronounced, and in still others, such as birch, maple, and yellow-poplar, there is practically no difference between springwood and summerwood, although the division between the rings is plain enough. The width of the summerwood also varies considerably in species such as Douglas-fir, the southern yellow pines, and the oaks according to the growing conditions at the time the summerwood was formed.

2.13. Sapwood and Heartwood.—In the living, tree, the sapwood layer, which is next to the bark, contains many living cells that serve mainly in the transfer and storage of food; most of its cells, however, are dead and serve only as channels for the movement of sap and to help support the tree. In the heartwood, which lies between the pith and the sapwood, all of the cells are dead and function mainly in supplying strength to the trunk.

Year by year, as a tree increases in diameter by addition of new layers of sapwood under the bark, the core of heartwood enlarges at substantially the same rate. The change consists principally in the death of living cells in the adjacent sapwood and its transformation into heartwood by the infiltration of coloring matter and various other materials into its cell walls and cell cavities.

In many woods there is a marked color difference between sapwood and heartwood, the latter being the darker (fig. 2-1). The pines, oaks, baldcypress, Douglas-fir, and birch are woods showing this contrast. Some woods, as for example, hemlock and spruce, show little or no color difference between sapwood and heartwood.

Sapwood may, however, be discolored by sapstaining, wood-destroying, and other fungi, chemical stains within the wood, and color leached from the bark. The color of the heartwood may be uniform or streaked and variegated, the latter condition often existing in sweetgum. The outer part of the heartwood of old Douglas-fir trees is often yellowish in color in contrast to the more reddish inner part of the trunk. Occasional light-colored zones known as internal sapwood occur in heartwood of Douglas-fir, Sitka spruce, Western redcedar, Western larch, and some other species. Decay may discolor heartwood in various ways.

The sapwood of practically all species is poor in decay resistance. This susceptibility of sapwood to decay is considered mainly due to lack of the toxic substances that are found in heartwood of durable species; for some of the stain and mold fungi the stored foods in the sapwood are also favorable.

The thickness of the sapwood layer varies considerably both between species and in logs of the same species. In Atlantic white-cedar, Western redcedar, Douglas-fir, and spruce it is usually less than 1½ inches thick and consequently constitutes but a relatively small part of the lumber cut from these species. In southern yellow pine, white ash, birch, and maple, on the other hand, the sapwood band is so thick that it often comprises more than half the total volume of the log.

Heartwood is fundamentally neither weaker nor stronger than sapwood, but there are some changes in physical characteristics, besides change in color, which accompany heartwood formation. After the timber is cut, the heartwood in most species is more resistant to the attack of certain insects and to decay, stain, and mold than is the sapwood. In the living tree, however, the sapwood is usually less subject to attack because it contains so much water, whereas specific fungi often infect the heartwood. The decay resistance of heartwood lum-

ber varies markedly among species, some woods having heartwood that is not much superior to sapwood while in others the heartwood is highly resistant to decay.

Heartwood is also as a rule less permeable than sapwood to liquids. For this reason, it is more difficult to treat with preservatives and seasons more slowly than sapwood. In resinous species, the heartwood usually contains more resin than the sapwood.

woods, such as southern yellow pine and Douglas-fir, are harder than some of the so-called hardwoods, such as basswood and cottonwood; but the terms have been in use so long that their meaning has been definitely established. Within each class there are considerable variations in structure.

Hardwoods as a class generally contain larger cells, constituting pores or vessels, scattered among the smaller cells, which are mostly

FIGURE 2–1.—Cross section of an oak log, showing dark heartwood within center light-colored sapwood band, annual rings, and bark.

2.14. Hardwoods and Softwoods.—All woods can be grouped in two general classes: hardwoods, which come from trees with broad leaves, and softwoods, or conifers, which come from trees with needlelike or scalelike leaves. The terms "hardwoods" and "softwoods" are not descriptively exact, since some of the so-called soft-

fibers. Figure 2–2 shows the pores and other cells in a hardwood cube highly magnified. In many hardwoods the pores can be seen distinctly as small holes on smoothly cut cross sections and as fine grooves on planed longitudinal surfaces. In other hardwoods the pores cannot be seen without magnification.

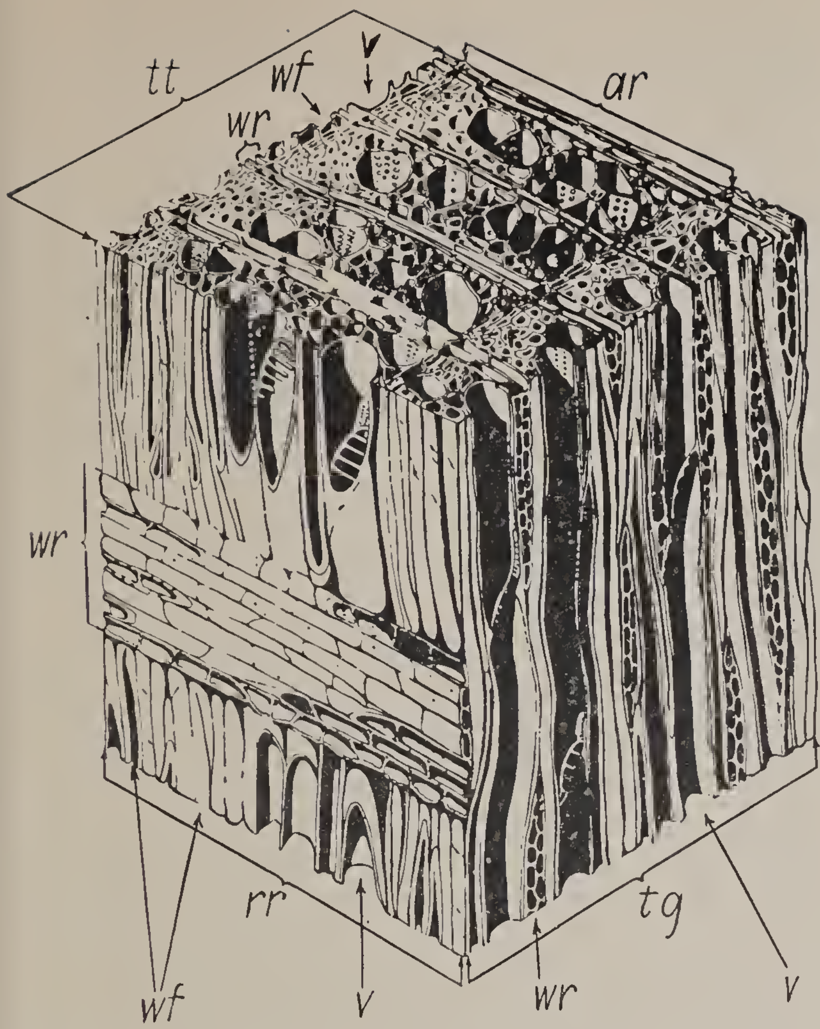

FIGURE 2–2.—Drawing of a small cube of hardwood highly magnified: *tt*, transverse surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *sp*, springwood; *sm*, summerwood; *wr*, wood ray; *wf*, wood fibers; *v*, vessels, or pores.

In certain hardwoods the pores in the heartwood and inner sapwood become more or less plugged with ingrowths from the neighboring cells, known as tyloses. The white oaks are among the principal species having tyloses, and the presence of these ingrowths is largely responsible for the watertightness of white oak.

The fibers in hardwoods are so small that they cannot readily be distinguished from one another with a hand lens. They average about one twenty-fifth inch in length. Strength of wood, however, does not depend upon fiber length. The thickness of the fiber walls and size of fiber cavities greatly affect their strength.

In addition to the vertically arranged cells, there are aggregations of horizontally elongated cells known as rays or wood rays, which extend radially from the bark inward. In oak the rays are distinctly visible as light-colored lines on the cross section (fig. 2–1) and as large "flakes" on radial surfaces (fig. 2–2). In all other native commercial species they are much smaller.

In softwoods the bulk of the wood is composed of fibrous cells called tracheids, averaging about one-fifth inch in length. Figure 2–3 shows a drawing of a small softwood cube highly magnified. On account of the absence of pores, the softwoods are called nonporous woods.

On a smoothly cut cross section the fibrous cells can be seen with a hand lens, resembling in their regularity the cells of a honeycomb, except that in the outer part of each annual ring they are flattened radially and thicker walled, producing the denser band of summerwood. Rays are present in softwoods as well as in hardwoods, but they are always small and on the cross section are invisible without a lens (fig. 2–3).

Resin ducts are passages extending vertically between fibrous cells and radially within certain rays. They serve for the storage and conduction of resin and in native woods are present normally only in the pines, spruces, larches or tamaracks, and Douglas-fir.

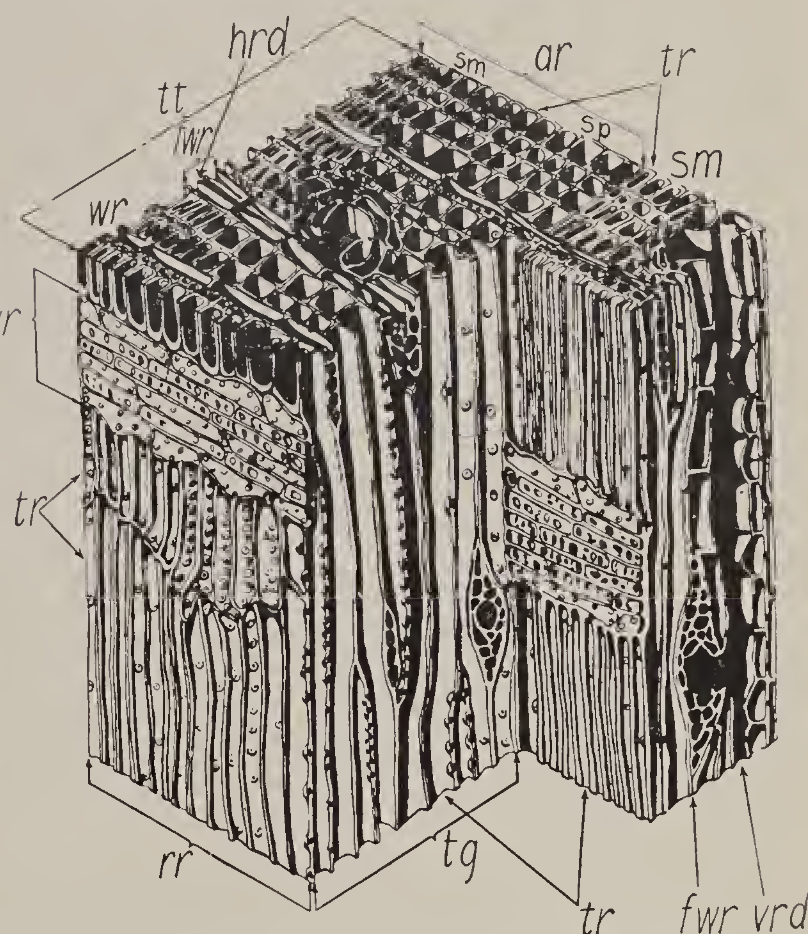

FIGURE 2–3—Drawing of a small cube of softwood highly magnified: *tt*, transverse surface; *rr*, radial surface; *tg*, tangential surface; *ar*, annual ring; *sp*, springwood; *sm*, summerwood; *tr*, tracheid, or fiber; *wr*, wood ray; *fwr*, fusiform wood ray containing horizontal resin duct; *hrd*, horizontal resin duct. The large hole near the center of the tranverse section and the passage along the right edge are vertical resin ducts, *vrd*.

2.2. CHARACTERISTICS OF HOUSING WOODS.

2.20. General.—Of the great variety and number of wood species that exist in the forests, relatively few have come into widespread use in housing. Basically, the properties of wood have dictated its choice but, to a great extent, custom and regional preferences have also played a part. Availability, of course, has also been an important factor, especially in more recent times. Thus, today the United States is very largely dependent upon the great Douglas-fir stands of the Pacific Northwest and the rapid-growing forests of the South for its framing lumber and plywood. The West also furnishes, in ponderosa pine, much of the millwork lumber used by the nation, as well as redwood and Western redcedar for siding.

Broadly speaking, the principal properties which determine the suitability of wood for various housing uses are: (1) strength and rigidity; (2) machinability and ease of working with tools; (3) ease of nailing and ability to hold fastenings of various kinds without splitting; (4) weathering resistance; (5) dimensional stability—freedom from excessive shrinking and swelling; (6) freedom from objectionable defects; (7) ability to take finishes; (8) resistance to wear; (9) decay resistance; and (10) pleasing appearance.

Obviously, no one kind of wood can be ranked superior in all of these properties. Douglas-fir, for example, is excellent in most strength properties and is therefore a desirable framing wood. It is not, however, as easy to work nor does it hold paint as well, for example, as ponderosa pine or Western redcedar, thus is less suitable for interior trim or exterior siding. On the other hand, its availability in large sizes for veneer manufacture has led to its widespread use for exterior grades of plywood despite the handicap of its relative deficiency in paint retention.

Wise selection of lumber involves first of all singling out the determining requirements of the job. Good judgment and keen insight applied in this connection yield high returns in ultimate satisfaction. After the requirements have been determined, it is relatively easy to check the properties of the different woods to see whether these requirements would be met. The following summary of general characteristics of the more important housing woods presents brief descriptions of their strength and other important properties.

2.21. Hardwoods.

2.2100. Ash. — The white *(Fraxinus americana)*, green *(F. pennsylvanica lanceolata)*, and black *(F. nigra)* are the important ashes of the 18 species native to the United States. White ash lumber comes principally from New England and the Middle Atlantic and Central States, green ash from the South Atlantic States and the Mississippi Valley, and. black ash from the Lake States. Oregon ash *(F. oregona)* is commercially produced in southwestern Oregon.

Commercial white ash, composed primarily of white and green ash, ranks high in weight, strength, hardness, and shock resistance, retains its shape, and wears well. Second-growth ash is usually of more rapid growth and tougher than old-growth ash. Black ash is somewhat lower in weight and strength than commercial white ash, hence is used more where other properties, such as workability, ability to bend easily, cleavage qualities, and capacity to take a finish, are important, as in furniture. The strength properties of Oregon ash rank between those of commercial white ash and black ash. The ashes are moderately low in decay resistance. They are not extensively used in housing but find some application as interior trim and structural framing lumber.

2.2101. Beech, American (Fagus grandifolia).—American beech grows throughout most of the area east of the Great Plains. Pennsylvania, New York, Michigan, Indiana, Ohio, and West Virginia produce the bulk of the beech lumber. The wood is heavy, hard, stiff, of fine, uniform texture, has good shock-resisting ability, and resists abrasion. It is low in resistance to decay. Mature trees attain a height of 120 feet and diameters of 2 feet or more. Its principal housing use is for flooring.

2.2102. Basswood.—Basswood *(Tilia glabra* and other species) is distributed over the eastern half of the United States, the greater portion of the lumber coming from the Great Lakes region. The wood is light in weight, low in strength, soft-textured, easily worked, and straight-grained. The heartwood is creamy brown and the sapwood creamy white, changing more or less gradually into the heartwood. The sapwood, especially when of rapid growth,

has a clean appearance. The lumber finds housing uses in enameled interior trim, cabinets, and shelving.

2.2103. Birch.—Of the 15 or 20 species of birch grown in the United States, yellow birch *(Betula lutea)* and sweet birch *(B. lenta)* are the most important for housing purposes. Both grow principally in the Lake States, the Appalachian Mountains, and the Northeastern States. They are cut without distinction for lumber.

Yellow birch has white sapwod and light reddish brown heartwood. Sweet birch has light brown sapwod and dark brown heartwood. The wood of both is heavy, hard, stiff, strong, and high in shock resistance, but low in decay resistance. It is of a fine, uniform texture and takes a beautiful natural finish. Its principal housing uses are as interior trim, doors, and flooring. Yellow birch is also made extensively in plywood form and is suitable for interior and flooring panels.

2.2104. Chestnut, American (Castanea dentata).—American chestnut, a species facing extinction by a bark blight, is today obtained chiefly from the southern Appalachian Mountain forest although it formerly was cut commercially as far north as southern New England. The wood of blighted trees is entirely satisfactory if the trees are cut before checking, insect attack, or decay begins. The sapwood band is narrow in the log, and its heartwood is highly resistant to decay. The wood is moderately low in weight and strength, straight-grained, and stays in place well. The tree reaches a height of 60 to 100 feet, and attains a diameter of 3 feet or more. Remaining stocks find use principally in millwork and as core stock for veneer panels.

2.2105. Cottonwood.—The name cottonwood is applied to 10 or 12 closely related species of trees that grow in the United States, of which Eastern cottonwood *(Populus deltoides)* and Northern black cottonwood *(P. trichocarpa hastata)* are the most important. Eastern cottonwood is widely distributed east of the Rocky Mountains and black cottonwood in the Northwest. The wood is light in weight, weak, and has a tendency to warp in seasoning. It has unusually uniform texture, works nicely, and does not split easily. The annual growth rings are scarcely noticeable. It decays quickly when in contact with the ground. It is used chiefly in housing for planing-mill products and large amounts are cut into veneer.

2.2106. Elm.—The three species constituting the greater part of the elm lumber produced in the United States are American *(Ulmus americana)*, slippery *(U. fulva)*, and rock elm *(U. racemosa)*. The growth range of American and slippery elm (sold as commercial soft elm) includes most of the area east of the Rocky Mountains. Rock elm is confined largely to the North Central States. Rock elm is heavy, hard, strong, and resists shock well. Two southern species of elm, cedar elm *(U. crassifolia)* and winged elm *(U. alata)* have properties similar to those of rock elm. Soft elm is lighter and has lower strength properties. In housing it is occasionally used for flooring and framing lumber.

2.2107. Hackberry.—The range of hackberry *(Celtis occidentalis)* extends from New England to Virginia and westward to eastern North Dakota, Iowa, southwestern Missouri, and western Kansas. Sugarberry *(C. laevigata)* occurs from Virginia to southern Florida and westward to eastern Texas, Arkansas, eastern Oklahoma, Missouri, eastern Kansas, southern Illinois, Indiana, Kentucky, and Tennessee. Sugarberry and hackberry are marketed together as hackberry. The annual reported cut is not large, but this is only a part of the total output, since it is often sold with the lower grades of ash and also sometimes with elm. The wood is moderately heavy and hard, rather weak as a beam, limber, and has good shock resistance. It is sometimes used for flooring, as in kitchens, and occasionally for roof boards.

2.2108. Magnolia.—Two principal species of magnolias furnish the bulk of the lumber used. Southern magnolia, also called evergreen magnolia *(Magnolia grandiflora)*, grows along the east coast from North Carolina to Florida and westward in the gulf coast region of Texas and through western Louisiana and southern Arkansas. The range of the cucumbertree *(M. acuminata)* extends from western New York to Alabama following the Appalachian Mountains, and westward to Illinois and Mississippi, with some in Arkansas. It attains largest size and greatest abundance in the valleys of eastern Tennessee and the western Carolinas. The wood of both species resembles that of yellow-poplar but is usually somewhat harder and heavier,

often with a light to dark purplish color. Much cucumbertree lumber and some Southern magnolia are marketed with the lower grades of yellow-poplar. Its principal housing uses are as planing-mill products and siding.

2.2109. Maple.—Of the 13 species of maple that grow in the United States, sugar maple *(Acer saccharophorum)* and black maple *(A. nigrum)*, jointly classed as hard maple, are by far the most important as well as the most abundant. Others of commercial importance are silver *(A. saccharinum)*, and red *(A. rubrum)*, which are commonly called soft maple, and bigleaf or Oregon maple *(A. macrophyllum)*, which belongs in the soft maple group on the basis of its properties. The commercial maples, as a group, grow throughout the eastern part of the United States with the exception of Oregon maple, which appears on the Pacific Coast. The heartwood of hard maple is light reddish brown and its sapwood white with a slight reddish brown tinge. The white maple of commerce is the unstained sapwood of sugar and black maple. The wood of these species is heavy, hard, strong, and stiff, has good resistance to shock, and wears well under abrasion, excelling the other maples in these properties. It has moderate shrinkage and uniform texture. The grain is usually straight but sometimes curly, wavy, or bird's-eye grain occurs. Both silver maple and red maple are lighter in color and not so heavy, hard, or strong as sugar maple. Silver maple is lighter in weight and weaker than red maple. The strength properties of bigleaf maple are intermediate between silver and red maple. Maple is used for flooring and other planing-mill products, interior trim, and sometimes for framing.

2.2110. Oak.—All the oaks of commercial importance, about 15 of the 60 or more native species, grow in the eastern half of the United States, especially in the Mississippi Valley and the South. In the lumber trade the oaks are commonly divided into two groups, red oak and white oak, and no attempt at a finer distinction is made in most cases.

The common and botanical names of commercial white oak are: white oak *(Quercus alba)*, chestnut oak *(Q. montana)*, swamp chestnut oak *(Q. prinus)*, swamp white oak *(Q. bicolor)*, post oak *(Q. stellata)*, overcup oak *(Q. lyrata)*, and bur oak *(Q. macrocarpa)*.

The common and botanical names of commercial red oak are: Red oak *(Quercus borealis)*, swamp red oak *(Q. rubra pagodaefolia)*, southern red oak *(Q. rubra)*, pin oak *(Q. palustris)*, black oak *(Q. velutina)*, water oak *(Q. nigra)*, and willow oak *(Q. phellos)*.

White oak heartwood is more durable and of lighter color than red oak. Furthermore, the pores in the heartwood of white oak are for the most part plugged with a growth called tyloses, which makes the wood much less permeable to liquids than that of red oak. Oak is commonly sold both plain and quarter-sawed, with advantages in each.

Oak is heavy, hard, stiff, and strong. Although there is no important difference between red and white oak in these properties, the oaks, like all other species, vary in their properties within a single species. Rapidly grown oak is generally stronger, harder, and tougher than slow-growth oak, which is finer-grained, softer, and more easily worked.

Flooring and interior trim consume a large part of the oak cut.

2.2111. Sweetgum.—Sweetgum *(Liquidambar styraciflua)* is a native of the swamp and bottom lands in the South that are dry for the greater part of the year.

Although its tendency to warp badly in seasoning long kept it out of commercial use, research ultimately found the proper methods of drying and handling, and in consequence the lumber, as produced by responsible manufacturers, has for years been a satisfactory commercial material. The color of the heartwood, which is sold as red gum, ranges from a light to a deep reddish brown. The sapwood, which is commercially called sap gum and looked upon as a distinct kind of lumber, is nearly white. The wood is moderately heavy and strong, of fine, uniform texture, and will take a beautiful finish. The heartwood is moderately durable. Sweetgum is used both in lumber and veneered form for interior trim, cabinets, doors, and occasionally, where available, for flooring and a little framing. On account of its fine, uniform texture, it is well suited for enameled woodwork.

2.2112. Sycamore.—Sycamore *(Platanus occidentalis)* grows widely in the eastern half of the United States, but the greater portion comes from the bottom lands along the Mis-

sissippi River and its tributaries. Sycamore is moderately heavy and moderately strong. The heartwood is reddish brown, and the sapwood is somewhat lighter in color. In quarter-sawed sycamore the rays are conspicuous, but the plain-sawed lumber has little figure. Seasoning the wood without warping is difficult, especially when it is plain-sawed. Sycamore is used principally for interior trim and fancy paneling. Where available, it is occasionally used for flooring and interior finish.

2.2113. Tupelo, Black (Nyssa sylvatica).—Black tupelo, known to the lumber industry more commonly as blackgum, is native to all States east of the Mississippi River. In the South it grows as far west as Texas. Black tupelo, along with water tupelo (known commercially also as tupelo gum) was not cut for lumber to any great extent until about 35 years ago. The lumber of black tupelo is largely sapwood, which is grayish white when dry, soft, of fine texture, moderately heavy, and moderately strong; it is, however, cross-grained, tends to warp, and is difficult to split. It is used in housing to some extent for flooring, inside finish, and cabinet work.

2.2114. Tupelo, Water (Nyssa aquatica).—Water tupelo closely resembles black tupelo in appearance and most other properties, and the two species are often sold in mixture even when marketed as one or the other, as there is no positive way of identifying them by the wood alone. Water tupelo has the same housing uses as black tupelo. It is somewhat harder and stronger than black tupelo.

2.2115. Walnut, Black (Juglans nigra).—Black walnut is found in commercial quantities chiefly in Missouri, Iowa, Illinois, Indiana, Ohio, Kentucky, and Tennessee, although it grows to some extent from New England to Texas. The heartwood, which is brown, varies from light to dark in color. The sapwood is nearly white. The wood is heavy, hard, strong, stiff, and has high resistance to decay. It stays in place well, takes stain and other finishes exceedingly well, and will also take a good polish. In addition, it is easily worked and glues satisfactorily. Black walnut is used largely for interior finish. Figured and the higher grade black walnut is extensively cut into veneer and used as faces in plywood and panel construction.

2.2116. Yellow-poplar (Liriodendron tulipifera).—Yellow-poplar is one of the largest native trees supplying lumber; under favorable conditions it reaches a diameter of 6 to 8 feet and a height of 100 to 160 feet. It grows throughout the eastearn part of the United States, with the largest stands in the southern Appalachian Mountains. The sapwood, frequently several inches in thickness, is white. The heartwood is yellowish brown with a greenish tinge. The wood is moderately light in weight, straight-grained, moderately soft, moderately weak, comparatively uniform in texture, easy to nail because it does not split readily, easy to glue, stays in place well, holds paint and enamel well, is easily worked, and finishes smoothly.

Yellow-poplar is especially suitable for finish, siding, and other products that are to be painted or enameled. It is largely used for planing-mill products, veneer, and panels. Some plywood is used for exterior purposes in prefabricated houses.

2.22. Softwoods.

2.2200. Baldcypress (Taxodium distichum).—Baldcypress, commonly called Southern cypress, is found in the low swamplands along the southeastern coast of the United States and as far up the Mississippi River Valley as Missouri. When grown in swamps near salt water, lumber from this species is called, by the trade, red cypress or tidewater red cypress, and the inland or upland growth is called yellow or white cypress. The heartwood from cypress near salt water will vary in color from slightly reddish to almost black, while that found farther inland is only slightly reddish or yellowish brown.

Southern cypress is moderately light and moderately strong, and the heartwood is highly decay-resistant. The wood is largely used where decay is an important factor. It holds paint well. Doors, sash, porch material, and siding are among its important housing uses.

2.2201. Cedars.—See redcedar, white-cedar, yellow-cedar.

2.2202. Cypress.—See baldcypress.

2.2203. Douglas-fir (Pseudotsuga taxifolia).—The properties of Douglas-fir are affected by the location of the stand. The strongest wood of this species grows in the coastal region of Washington, Oregon, and California, the intermediate class grows in the Inland Empire of northwestern Montana, northern Idaho, eastern Washington, and the northeastern tip of Oregon as well as the mountains of California, and

the least strong grows in the Rocky Mountains. Douglas-fir from the Inland Empire is often sold as larch and fir; that from the Rocky Mountains is often sold as red fir. Most of the lumber sold as Douglas-fir comes from the coast region.

Some Douglas-fir trees in the coast region are very large—up to 8 feet in diameter breast high. On rare occasions trees up to 14 feet are found. The quality of the wood in different portions of these trees varies greatly. Lumber from the top of the tree usually has more knots and is less dense than the butt cut. Lumber from the center of the average log, which is usually of more rapid growth than the rest of the tree, is consumed mostly in light construction, although some boxed-heart timbers of large size and ties are cut from such logs. The strongest structural timbers from these large logs are sawed farther from the center, where the wood is of slower growth. Nearer the bark the wood is frequently of still slower growth; it is softer, more uniform in texture, and the outer heartwood is more yellowish in color. This wood is used for interior and exterior trim, flooring, doors, long ladder rails, and similar products.

Douglas-fir in the form of lumber and timbers is one of the most desirable native woods for structural purposes. Large quantities are cut into veneer for plywood and other purposes. It is strong, moderately hard and heavy, and the heartwood is moderately durable. In general, it has a tendency to check and split and does not hold paint well, although its paint retention can be materially improved with a suitable primer, such as aluminum paint (sec. 7.400). It is extensively used for framing, flooring, interior trim, roof boards, siding, subfloors, sheathing, sash, and shelving.

2.2204. Fir, White (Abies concolor).—White fir and grand fir *(A. grandis)* are both known commercially as white fir. Grand fir is cut mainly in Idaho and in California near the coast, and true white fir in the mountain region of California.

Commercial white fir is light in weight and moderately low in strength, moderately soft, straight-gained, of medium and fairly uniform texture, nonresinous, and easily worked. Its resistance to decay is low. The sapwood and heartwood are white with a faint reddish tinge and are not distinguishable from each other. It is whiter in color than any other commercial softwood.

The chief consumption of this wood is in the construction of small houses, largely as framing and sheathing, roof boards, and subfloors. Other uses are for general millwork and planing-mill products.

2.2205. Hemlock, Eastern (Tsuga canadensis).—Eastern hemlock grows principally in the Lake States and in the mountains in the eastern part of the United States. The wood is pale buff in color with a reddish tinge, is moderately light in weight, and moderately low in strength. It has a tendency to splinter, is subject to ring shake, and is not decay resistant. The lumber is nonresinous, holds nails well, and the knots are characteristically small. Eastern hemlock is used largely for framing, sheathing, roofing, and subflooring. In the nominal 2-inch size the stock is cut extra thick, thus party equalizing the greater strength of some other structural woods.

A small amount of tamarack *(Larix laricina)*, a species heavier and stronger than Eastern hemlock, is sawed into lumber and is often sold with Eastern hemlock.

2.2206. Hemlock, Western (Tsuga heterophylla).—Large stands of Western hemlock extend along the Pacific coast from Alaska to northern California, penetrating farther inland just below the Canadian boundary than elsewhere. This species, which is sold commercially as west coast hemlock, is distinct from Eastern hemlock.

Western hemlock is a uniform fine-textured wood and is comparatively free of ring shakes. It is moderately light in weight, moderately high in strength properties, usually is straight-grained, and is nonresinous; its many small black knots are ordinarily fixed firmly in place. Its resistance to decay is low.

Western hemlock is used largely in house construction for framing, sheathing, and subfloors. Large quantities go also into siding, ceiling, flooring, and shiplap. Other uses are sash, doors, blinds, and general millwork.

2.2207. Larch, Western (Larix occidentalis).—Western larch is native principally to the Inland Empire. The heartwood is reddish brown, and the sapwood, which usually is not more than 1 inch thick, is yellowish white. In its natural color the wood finishes well, but it does not hold

paint well. The wood splits easily and is subject to ring shakes. Knots, although common, are usually small. Its resistance to decay is moderate. It is rated as moderately heavy, strong, stiff, and moderately good in shock resistance. Western larch and Douglas-fir are logged together and are frequently manufactured, graded, and sold together as larch-fir.

Western larch is used largely in building construction as framing, small timbers, planks, and boards. Planing-mill products, sash, and doors take a small portion of it. Its use as an interior trim is increasing because of its pleasing appearance and ease of finishing.

2.2208. Pine, Eastern White (Pinus strobus).—Eastern white pine, originally known as "white pine," is found principally in the Lake States, the Northeastern States, and the Appalachian region. The sapwood is white, and the heartwood ranges from cream to light reddish brown. The wood is moderately light in weight, moderately low in strength, and usually straight-grained. The soft, uniform texture of the virgin growth has won for it extensive use in building and millwork. Changing dimension little with changes in moisture content and easily worked, the species makes a desirable wood for molds and templates. The second-growth pine is usually of faster growth, and more knotty than old growth. Virgin growth is becoming scarce.

Red, or Norway, pine (*Pinus resinosa*) of the Lake States, although belonging to the yellow pine group, is sold with Eastern white pine in the lower common grades. It is somewhat coarser in grain and texture, however, has more strongly marked annual rings, is heavier and stronger, and is somewhat more resinous.

2.2209. Pine, Ponderosa (Pinus ponderosa).—Ponderosa pine grows from Washington to the Black Hills and southward in the Rocky Mountain and Pacific Coast regions.

The wood is moderately light in weight, moderately low in strength, and ranks relatively low in shrinkage. It is easy to work, stays in place well, and has a fairly uniform texture, being somewhat comparable in these respects with the white pines.

The principal housing uses of ponderosa pine are for sash and frames, doors, general millwork, and building construction.

2.2210. Pine, Southern Yellow.—Commercial southern yellow pine, in one species or another, grows in the Atlantic and Gulf States from New Jersey to Texas and as far North as Pennsylvania, West Virginia, Kentucky, and Missouri. Although a large part of the original stand has been cut, the amount remaining, the rapidity of growth, and the ease of reproduction assure an adequate supply for many years, if not indefinitely.

Southern yellow pine is a general name for a number of closely related species, chiefly longleaf (*Pinus palustris*), shortleaf (*P. echinata*), loblolly (*P. taeda*), slash (*P. caribaea*), and pond pine (*P. rigida serotina*). Except for the fact that the pith often distinguishes longleaf from loblolly, shortleaf, and slash pines, the species cannot be positively distinguished by the wood alone. Both longleaf and shortleaf structural timbers are highly desirable for structural purposes (sec. 4.0212). The wood is dense, moderately hard, strong, and the heartwood is moderately durable.

Southern yellow pine lumber of low density, although lacking the strength of dense stock, is more desirable for some purposes, such as interior trim. It checks less than the dense stock, is more easily worked, splits less in nailing, often holds a coating of finish better, is superior in thermal insulation, and because of lighter weight may be handled and shipped at lower cost. Uses for the low-density stock include framing, sheathing, floor boards, and millwork. Southern yellow pine is an excellent general utility wood. In general, it has a tendency to check and split; and it does not hold paint well, although its paint retention can be materially improved with primer coats (sec. 7.400).

The wide-ringed, light-weight, easily worked, and soft southern yellow pine lumber of comparatively low strength that is grown in the Atlantic Coastal Plain is largely loblolly and is known as North Carolina pine, and the soft, easily worked pine of uniform texture and low strength, produced chiefly from shortleaf stands in or near the Ozark Mountains, is called Arkansas soft pine.

The sapwood of all the southern yellow pines is easily treated for preservation, and pieces containing a large proportion of sapwood are readily obtained.

2.2211. Pine, Sugar (*Pinus lambertiana*).—Sugar pine is native to California and southern Oregon. It is similar in appearance and properties to Eastern white pine, but can usually be distinguished by its more conspicuous resin ducts. Sugar pine is the largest of the species of the white pine group, and the bulk of the exceptionally wide, thick stock of soft pine lumber is cut from this species. A large part goes into the manufacture of planing-mill products, such as sash, blinds, and drainboards. It is used interchangeably with Eastern white and Western white pine for many purposes.

2.2212. Pine, Western White (*Pinus monticola*).—Western white pine, sold commercially as Idaho white pine or Idaho pine, grows principally in northern Idaho, eastern Washington, and western Montana. Western white pine resembles Eastern white pine so closely that the clear wood of the two is indistinguishable. Both are regarded highly for their workability.

Western white pine is light in color, moderately light in weight, and straight-grained. It swells and shrinks a little more with changes in moisture content, but on the whole compares favorably with Eastern white pine and is largely used for the same purposes.

2.2213. Redcedar, Western (*Thuja plicata*).—Western redcedar is an important tree in the humid regions along the North Pacific coast and extends inland from Washington to Montana. The heartwood is reddish brown, and the narrow sapwood is white. The wood is light in weight, easily worked, rather soft and weak, has very little shrinkage, and the heartwood is highly resistant to decay. Western redcedar is a valuable wood for shingles, siding, and other uses where durability and ease of working are important factors. It holds paint well.

2.2214. Redwood (*Sequoia sempervirens*).—The commercially important stands of redwood are chiefly confined to a narrow belt, 10 to 30 miles wide, that extends from southern Oregon to within a few miles of San Francisco. The redwood forest in a small area south of San Francisco is also of commercial importance.

The heartwood of redwood varies in color from cherry to dark mahogany, and the sapwood, which is very narrow, is almost white. Many of the redwoods are extremely large, individual trees commonly reaching diameters of 5 to 10 feet. Exceptional trees attain a diameter of 20 feet or more. Such size permits a high percentage of clear lumber, and unusually wide clear boards are easily obtained. Redwood is moderately light in weight and moderately strong. The heartwood is especially valuable where resistance to decay is important because of its high durability. It has low shrinkage, stays in place well, and is not difficult to work.

Redwood is used for sash, doors, frames, siding, and interior and exterior finish. It holds paint well.

2.2215. Spruce, Eastern.—The term "Eastern spruce" includes three species, red *(Picea rubens)*, white *(P. glauca)*Q and black spruce *(P. mariana)*. White spruce and black spruce grow principally in the Lake States and New England, and red spruce in New England and the Appalachian Mountains. All three species have about the same properties, and in commerce no distinction is made between them. The wood dries easily, stays in place well, is moderately light in weight and easily worked, has moderate shrinkage and a moderate degree of strength, stiffness, toughness, and hardness. Eastern spruce is not resistant to decay. The wood is light in color, and there is little difference between the heartwood and sapwood. Eastern spruce is used principally for framing material and general millwork. Engelmann spruce, which grows throughout the Rocky Mountain and Cascade Ranges, is a lighter and weaker wood than the other spruces listed here. Some is cut locally for house framing, sheathing, subfloors, and other rough lumber.

2.2216. Spruce, Sitka (*Picea sitchensis*).—Sitka spruce grows in a narrow strip, seldom more than 40 miles wide, along the Pacific coast from Alaska to northern California. The wood is light in weight and has a moderate degree of hardness, stiffness, toughness, and strength. It ranks high in strength for its weight, and can be obtained in clear, straight-grained pieces of large size and uniform texture. The wood dries easily, stays in place well, has moderate shrinkage, and is easily worked. It is not resistant to decay.

Sitka spruce is used for sash, doors, siding, ceiling, flooring, and exterior and interior finish.

2.2217. White-cedar.—The term "white-cedar" usually includes the two species, Northern *(Thuja occidentalis)* and Atlantic white-cedar

(Chamaecyparis thyoides). Northern white-cedar, which is of little importance for lumber because the tree is small, grows in the Lake States and in the Northeastern States. Atlantic white-cedar is a medium-sized tree that grows in the eastern part of the United States, near the coast. Both woods are very light in weight, of low shrinkage, and are soft and weak. They split readily, have a characteristic aromatic odor, and their texture is fine and uniform. The heartwood, which is highly resistant to decay, is light brown in both species, but that of Atlantic white-cedar has a reddish tinge. The sapwood is lighter in color than the heartwood, sometimes nearly white.

Atlantic white-cedar contains many knots and is made largely into siding, porch lumber, and shingles. Its odor resembles that of Eastern redcedar *(Juniperus virginiana)*; in fact, locally it is called "juniper." Eastern redcedar is commonly used for lining closets.

2.2218. White-cedar, Port Orford (Chamaecyparis lawsoniana).—Port Orford white-cedar grows naturally only in a narrow belt bordering the coast of southern Oregon and northern California. The heartwood, which is highly resistant to decay, is light yellow to pale brown in color, and the usually thin sapwood is of similar appearance. The wood is moderately light in weight, of moderate strength and hardness, is of a fine and unusually uniform texture, and has a spicy odor.

The wood is used for venetian blinds, interior finish, siding, and shingles. The lower grades are consumed for general construction purposes.

2.2219. Yellow-cedar, Alaska (Chamaecyparis nootkatensis).—Alaska yellow-cedar grows in the Pacific coast region of North America from southwestern Alaska to northern Oregon. In Washington and Oregon it is usually confined to the western side of the Cascade Mountains.

The wood is of a fine uniform texture and has very small shrinkage. It is moderately light and moderately low in strength. It has excellent working and finishing properties and ranks high in resistance to decay. The heartwood is a bright, clear yellow, and the thin, scarcely distinguishable sapwood is a shade lighter. A large part of the cut is used locally for interior finish and cabinet work.

2.3. DEFECTS AND BLEMISHES.

2.30. General.—A defect is any irregularity occurring in wood that may lower its strength. A blemish is anything, not necessarily a defect, that mars the appearance of wood. Thus, decay is a defect because it impairs wood's strength; certain stains, on the other hand, do not affect the strength of wood appreciably, their chief objection being that they discolor the wood.

Decay must be guarded against when selecting wood for any part of a house. Other defects become increasingly important as the size of wood members, especially structural framing members, is reduced. Thus, the trend in prefabrication toward use of smaller studs and joists in wall, floor, and ceiling panels places greater emphasis upon the selection of framing and cover materials that are comparatively free from defects. Lumber for conventionally constructed houses or their prefabricated equivalents is selected largely upon the basis of lumber grades (ch. 4), under which mill-run lumber is segregated according to the defects it contains. Proper grading, therefore, largely eliminates the serious defects from consideration when the correct grade is used. Nevertheless, when it becomes necessary to use grades lower than those recommended for specific uses in housing, the conscientious builder sorts his stock to the best advantage for various uses on the basis of defects present. The use of substandard grades is not, however, recommended, because selection of usable pieces entails too much waste of lumber, time, and labor.

The description of the more common wood defects and blemishes which follows is applicable to both lumber and plywood. Some are present in practically all species of wood, while others occur in only a few species.

2.31. Knots.—A knot is a portion of a branch or limb embedded in the tree. Normally a knot starts at the pith and increases in diameter from the pith outward as long as the limb is alive. Occasionally, knots start at some distance from the pith as a result of the development of dormant shoots.

As long as a limb remains alive, its fibers interlace with those of the tree trunk, producing an intergrown knot (fig. 2-4). Many of the lower limbs die, however, at some intermediate stage of the tree's growth as a result of shading or other causes, but they may not break off for

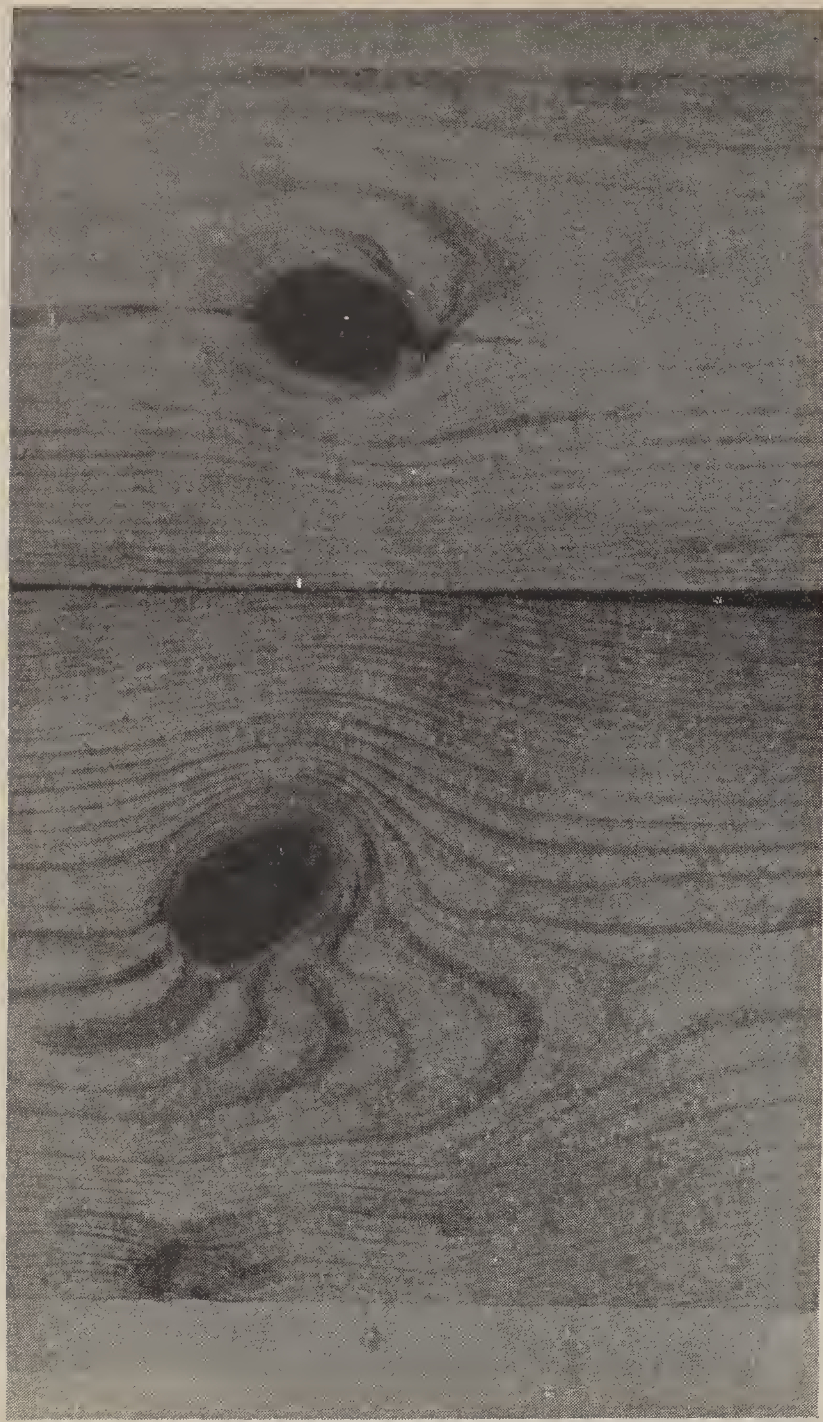

FIGURE 2-4.—Intergrown knots.

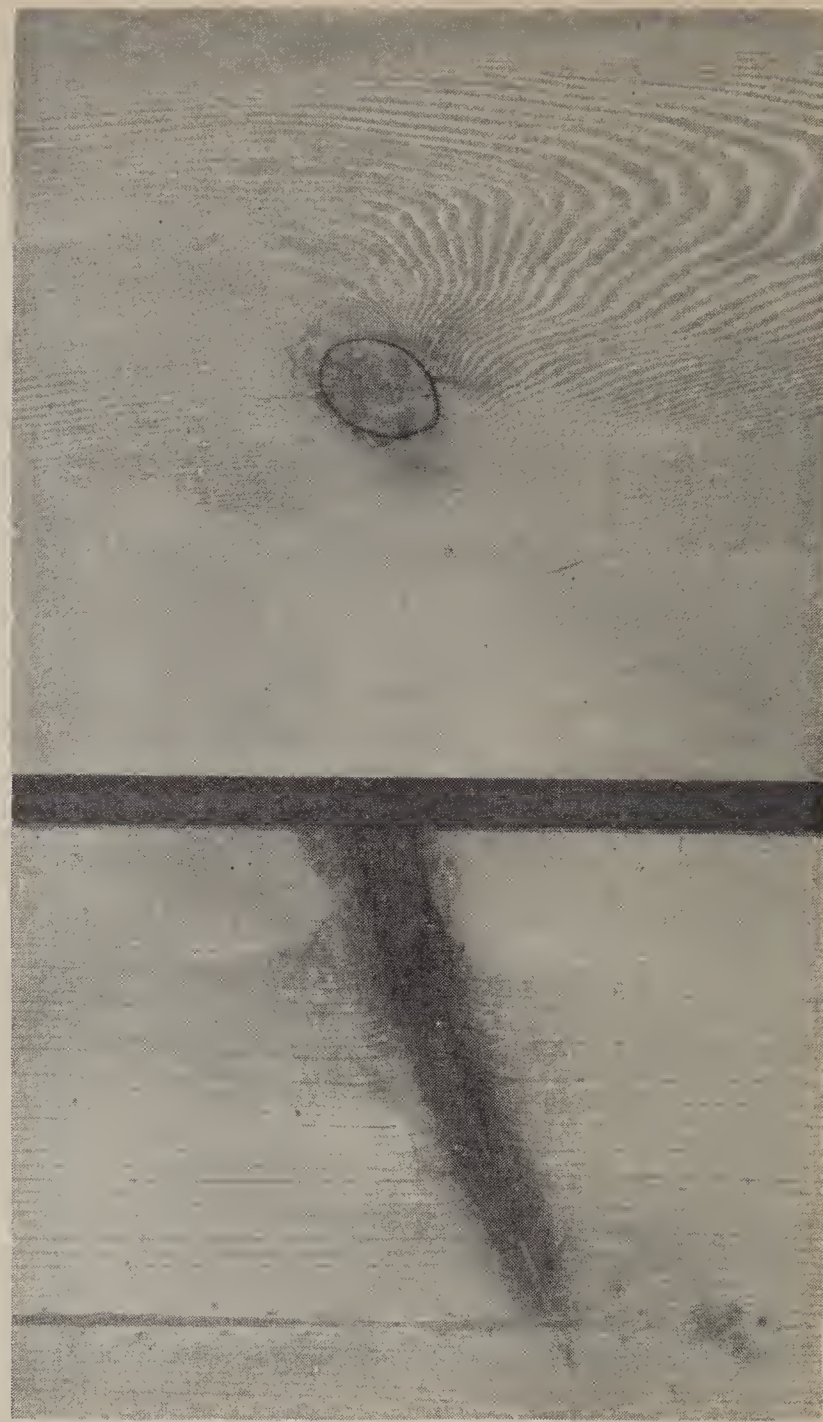

FIGURE 2-5.—Above, an encased knot; below, a spike knot intergrown for most of its length.

many years thereafter. After the death of a limb the wood formed in the tree trunk makes no further connection with it but grows around it, producing a dead knot, which may be either loose, so that it will drop out, or encased, so that it is held in position when the trunk is sawed into lumber (fig. 2-5).

Eventually, the dead limb breaks off, the stub heals over, and the distortion of grain in successive growth layers becomes less and less with increasing diameter of the trunk, until finally clear wood with normal grain is produced in the wood covering the knot.

A knot cut through transversely is known as a round knot, one cut through obliquely is known as an oval knot, and one cut through lengthwise is known as a spike knot (figs. 2–4 and 2–5). A sound, tight knot is solid across its face, at least fully as hard as the surrounding wood, shows no sign of decay, and is so fixed by growth or position that it will firmly retain its place in the piece. A watertight knot is one intergrown on at least one surface of the piece and sound on that surface.

Knots occur singly, in clusters, and as branch knots. A cluster of knots consists of two or more grouped together as a unit with the wood fibers deflected around the entire unit; a group of single knots does not constitute a knot cluster. Branch knots are two or more knots branching from another knot.

Knots are objectionable on account of the distortion and the discontinuity of the grain

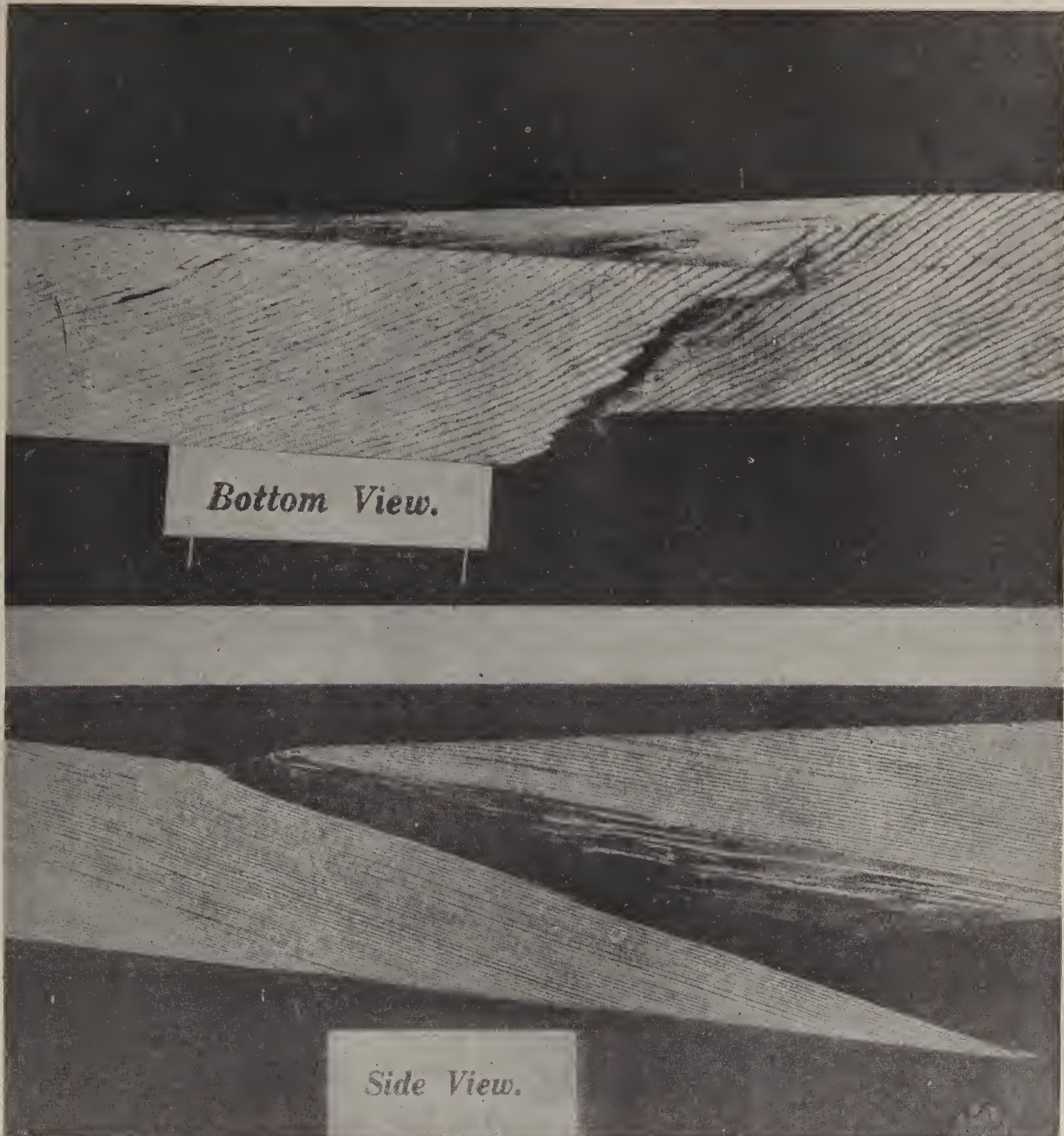

FIGURE 2–6.—Typical break in diagonal-grained specimen.

which they cause in lumber, thereby weakening the wood, causing irregular shrinkage, and making the machining difficult. In resinous species, pitch often exudes more freely from knots than from the clear wood. When lumber dries, the knots tend to become checked or loosened because of the difference in shrinkage of the knot and the surrounding wood.

In determining the size of a knot, only the knot itself is measured; the distorted grain around it is not included in the measurement because it is difficult to determine the exact boundaries of the surrounding distorted wood and specifications are based upon the size of the knot proper. A knot one-half inch or less in diameter is called a pin knot; one that is more than one-half and up to three-fourths inch in diameter is a small knot; a medium knot is more than three-fourths inch but not more than 1½ inches in diameter; and a large knot is more than 1½ inches in diameter.

2.32. Cross Grain.—A piece of wood is called cross-grained when the fibers are not parallel with the major axis or the sides of the piece.

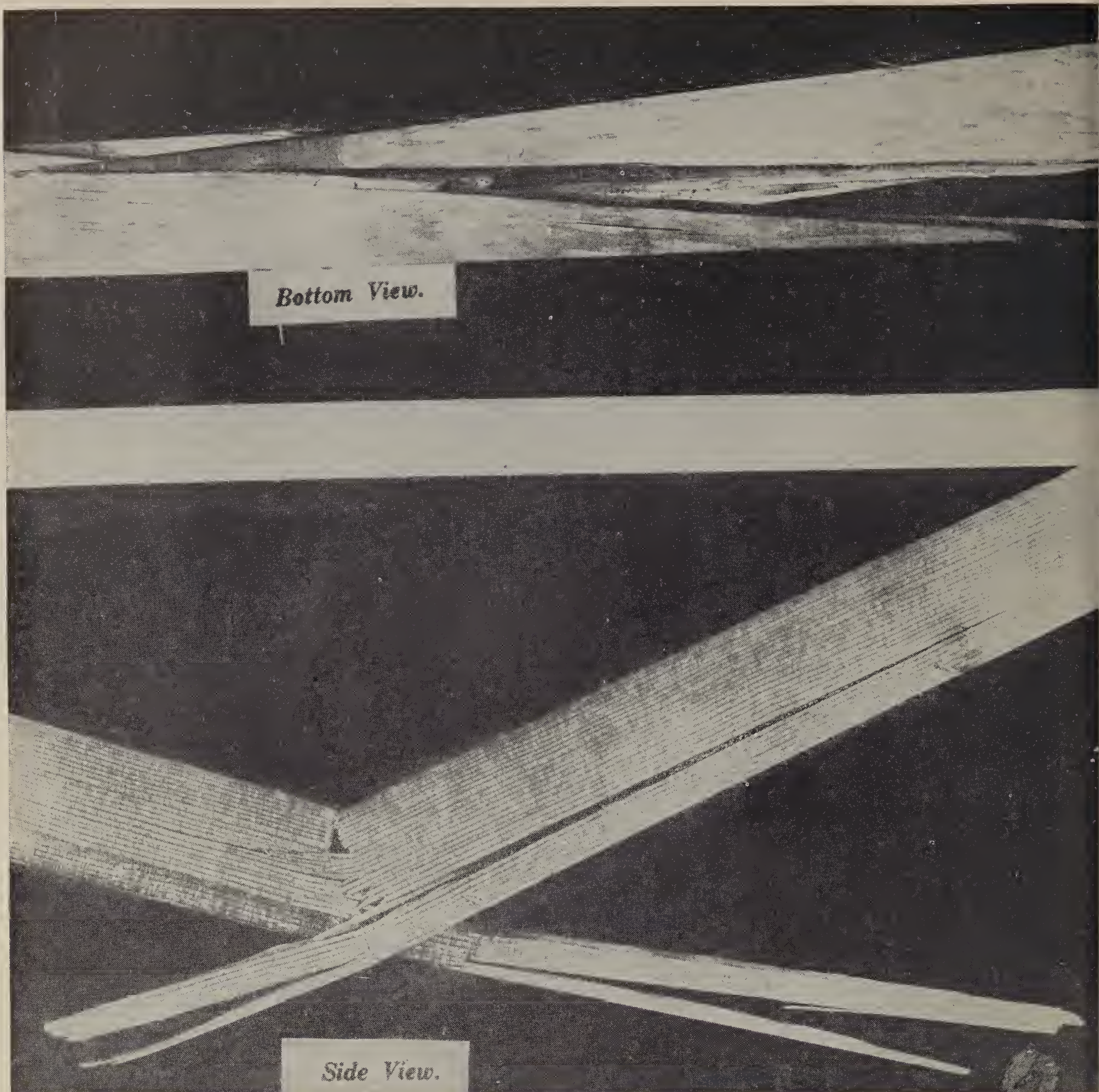

FIGURE 2–7.—Typical break in spiral-grained specimen.

Excessive slope of grain is objectionable because it reduces strength (sec. 5.2), causes warping in drying, makes smooth surfacing difficult when the wood is planed against the grain, creates gluing difficulties, and causes uneven penetration of stain.

Slope of grain is conveniently measured in inches of deviation from straightness within a definite length *(2–2)*. A deviation, or slope, of 1 inch in a length of 10 inches is steeper than a slope of 1 inch in a length of 15 inches. Slope-of-grain limitations are usually expressed as 1 in 15, 1 in 20, and so on; the unit of measurement may be the inch, the centimeter, or some other unit of length.

Cross grain may be either of two major types, diagonal grain (fig. 2–6) or spiral grain (fig. 2–7).

Diagonal grain is deviation of the plane of the annual rings from parallelism with the

FIGURE 2-8.—Straight grain and right-hand spiral indicated by direction of seasoning checks in dead tree trunks.

longitudinal axis of a piece of wood. It is due to such natural causes as crook, bulges, butt swell, pitch pockets and bark pockets, blister grain, some types of curly grain, healing over of knots and injuries, and to the common practice of sawing tapered logs parallel to the pith instead of to the bark.

Spiral grain occurs when, due to an unknown cause, the fibers in a tree are not vertical but follow a spiral course similar to the stripes on a barber pole or stick of candy. Spiral grain in peeled posts, poles, or tree trunks is evidenced by inclined rather than vertical season checks, as in the dead tree to the left in figure 2-8. The slope of the spiral also sometimes fluctuates, especially near the butt of the tree, so that a block split radially will show a ruffled or fluted appearance, as in figure 2-9.

Truly straight-grained lumber cannot be produced from spiral-grained trees, but with wide flat-sawn boards or cants sawed some distance from the pith, the slope of the spiral can be reduced by proper attention in edging and ripping such pieces into smaller ones. On the other hand, false or artificial spiral grain is produced when straight-grained timber is not cut parallel to the fibers as seen on the tangential surface. Superficially, it has the appearance of natural spiral grain and should be similarly regarded.

The principal indicators of the fiber direction on a truly tangential (plain-sawed or flat-grained) surface are checks, pores, resin ducts (fine brownish lines in the pines, spruces, Douglas-fir, and tamarack), wood rays (most conspicuous in the oaks), the direction in which

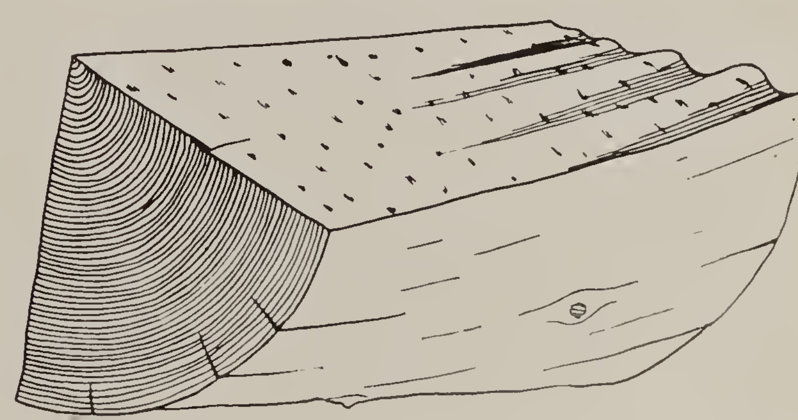

FIGURE 2-9.—Spiral grain of varying or fluctuating slope indicated by split radial surface.

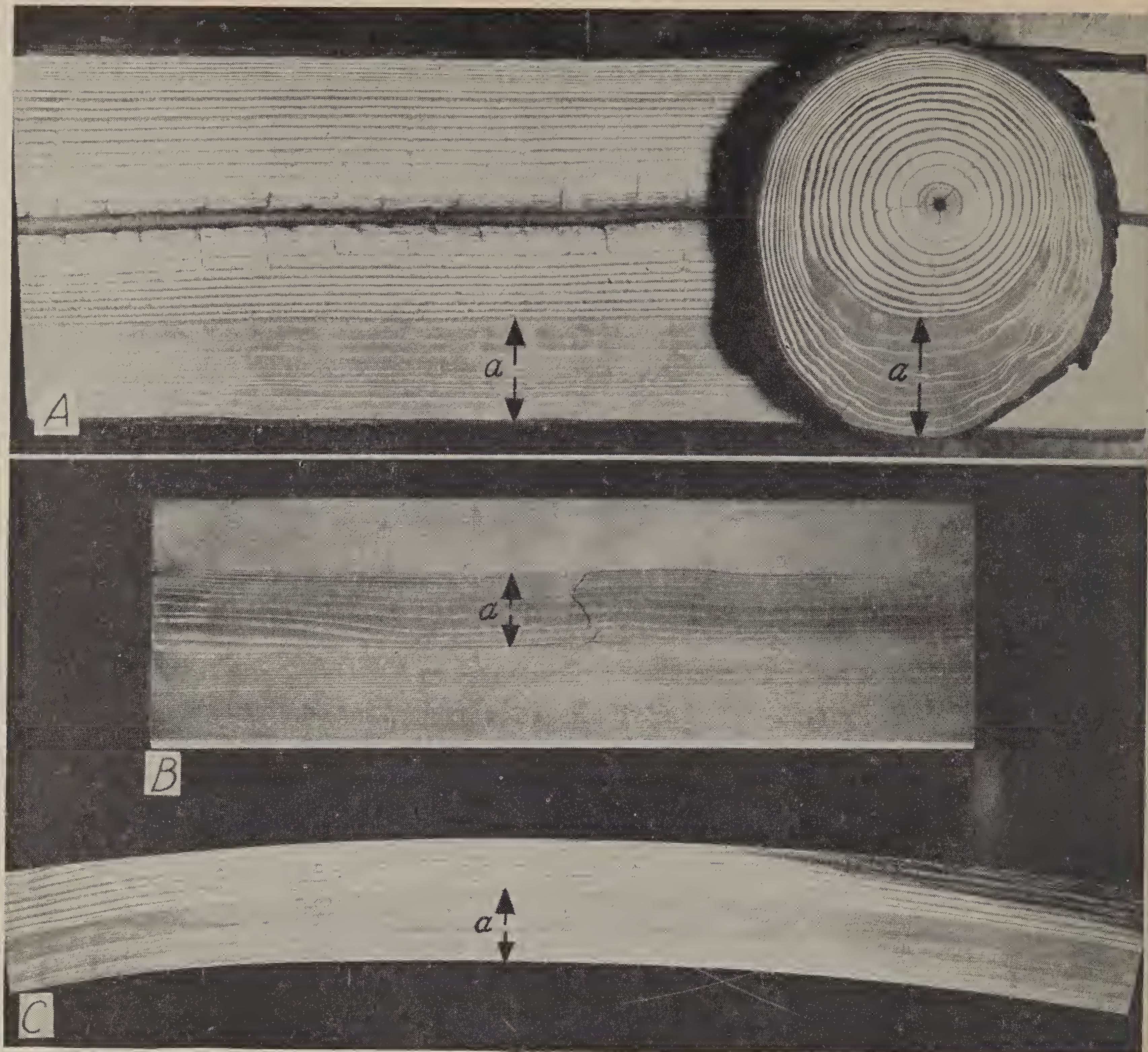

FIGURE 2-10.—*A*, Longitudinal and cross sections through tree trunk with compression wood on lower side; *B*, cross break in compression wood and splits between compression wood and normal wood due to greater longitudinal shrinkage of compression wood; *C*, crook caused by longitudinal shrinkage of compression wood on one edge of a piece. Compression wood is indicated by arrows and the letter "a."

a free-flowing ink or dye spreads, and the surface splits formed when a sharp-pointed tool, such as a chisel, is pushed into the piece and pried against the wood.

2.33. Compression Wood.—Leaning softwood trees usually develop on their lower sides abnormal wood called compression wood *(2–3)*. Such wood has relatively wide annual rings and unusually wide summerwood which, however, does not appear so dense and hornlike as normal summerwood. The resulting lack of contrast with springwood gives a lifeless appearance to compression wood, particularly when dry (fig. 2–10). On lumber surfaces compression wood usually has a yellowish or slightly brownish color when dry and a reddish color when wet. Streaks of compression wood frequently are interspersed in normal wood. Well-developed compression wood usually can be detected by ordinary visual inspection.

Compression wood shrinks excessively in the longitudinal direction. When compression wood

is present in the same piece with normal wood, the unequal endwise shrinkage causes bowing and crooking. Occasionally, excessive and irregular shrinkage causes cross breaks.

Most strength properties of compression wood are lower than those of normal dry wood. In bending, compression wood breaks with a brittle fracture, while normal wood splinters (fig. 2–11).

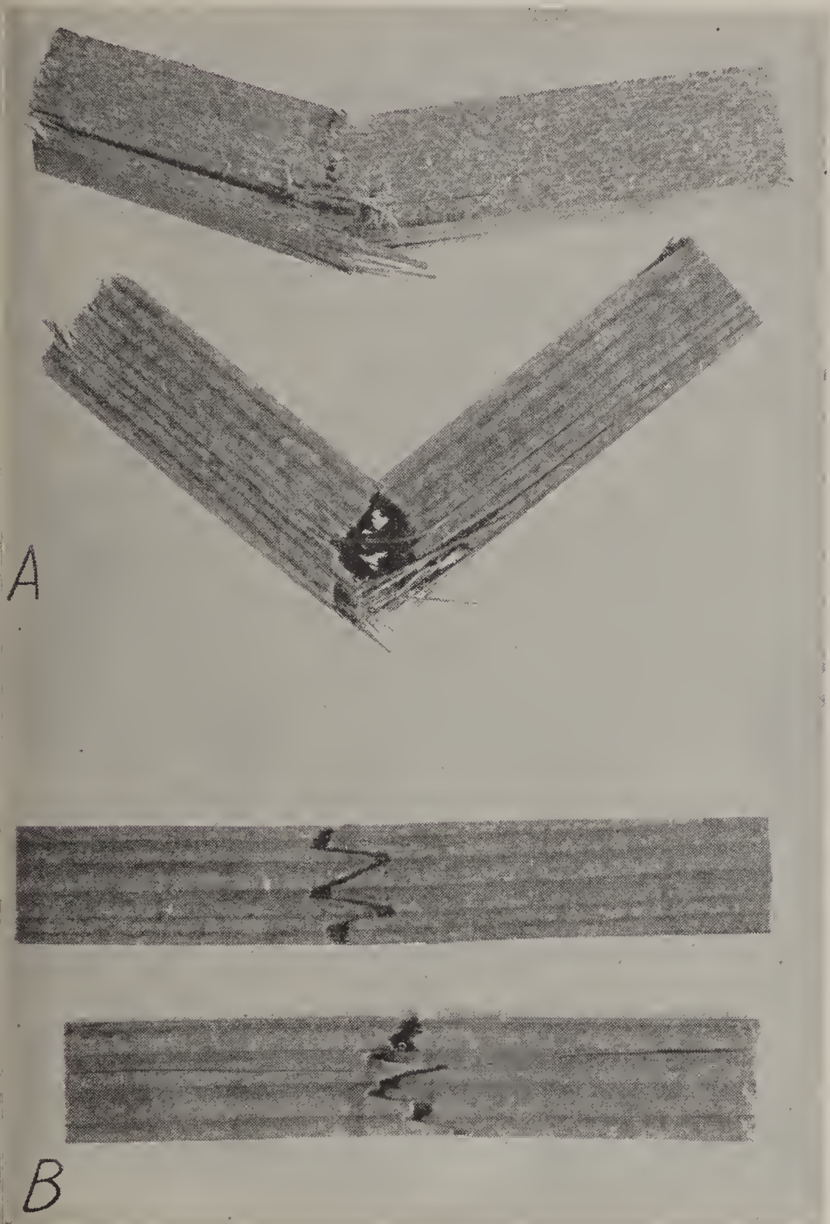

FIGURE 2–11.—Typical bending failure represented by *A*, splintering normal wood, and *B*, brittle compression wood.

2.34. Checks, Splits, and Shakes.—A check is a longitudinal crack in wood, generally in the radial direction or across the annual rings (fig. 2–12). Checks are usually due to uneven shrinkage in seasoning. Thick lumber checks more severely than thin lumber and wide lumber more severely than narrow lumber.

A small surface check is a perceptible opening not over 4 inches long; a medium surface check is not more than one thirty-second inch

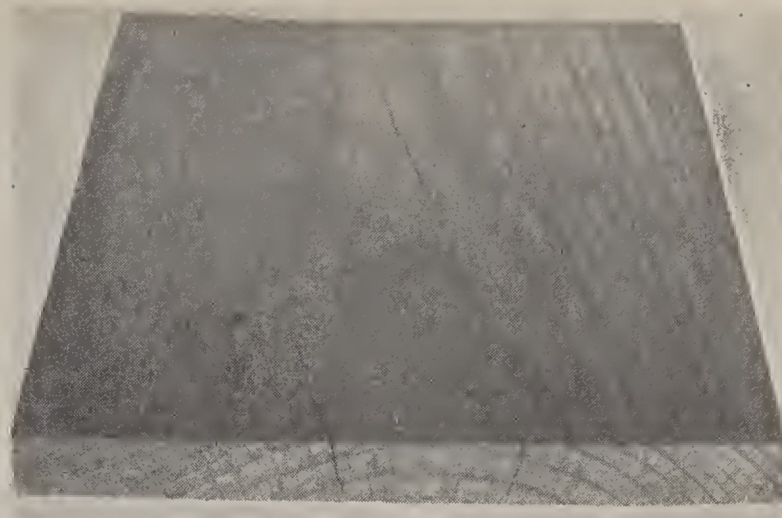

FIGURE 2–12.—Checks in a flat-grain board.

wide and between 4 and 10 inches long; and a large surface check is more than one thirty-second inch wide and more than 10 inches long.

A split is a lengthwise separation of the wood extending from one surface through the piece to the opposite surface or to an adjoining surface. Thick lumber does not split so readily as thin stock. A short split is one whose length does not exceed either the width of a piece or one-sixth its length; a medium split exceeds the width of a piece but not one-sixth its length; a long split exceeds one-sixth the length of the piece.

A shake is a longitudinal crack in wood following the annual rings (fig. 2–13). Shakes, unlike checks and most splits, do not develop in seasoning or handling but originate in green timber. They may, however, become accentuated in seasoning. They are more prevalent near the pith or heart center of the tree and consequently occur chiefly in lower grades of lumber. A fine shake is one with a barely perceptible opening; a slight shake is one not more than

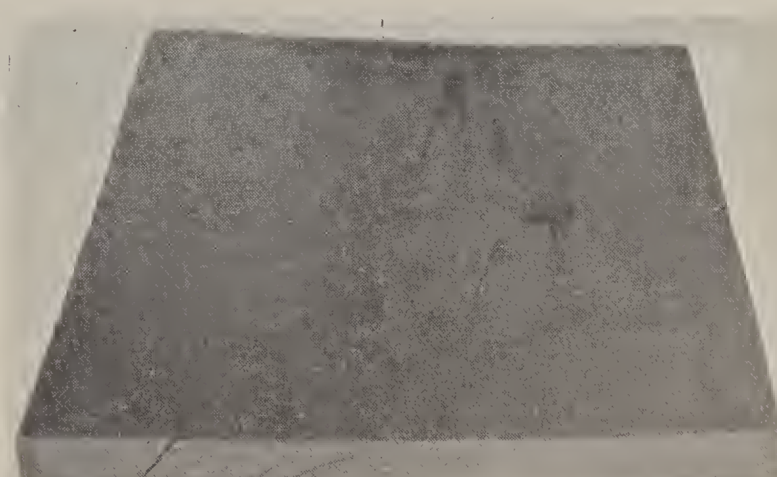

FIGURE 2–13.—Shake in a flat-grain board.

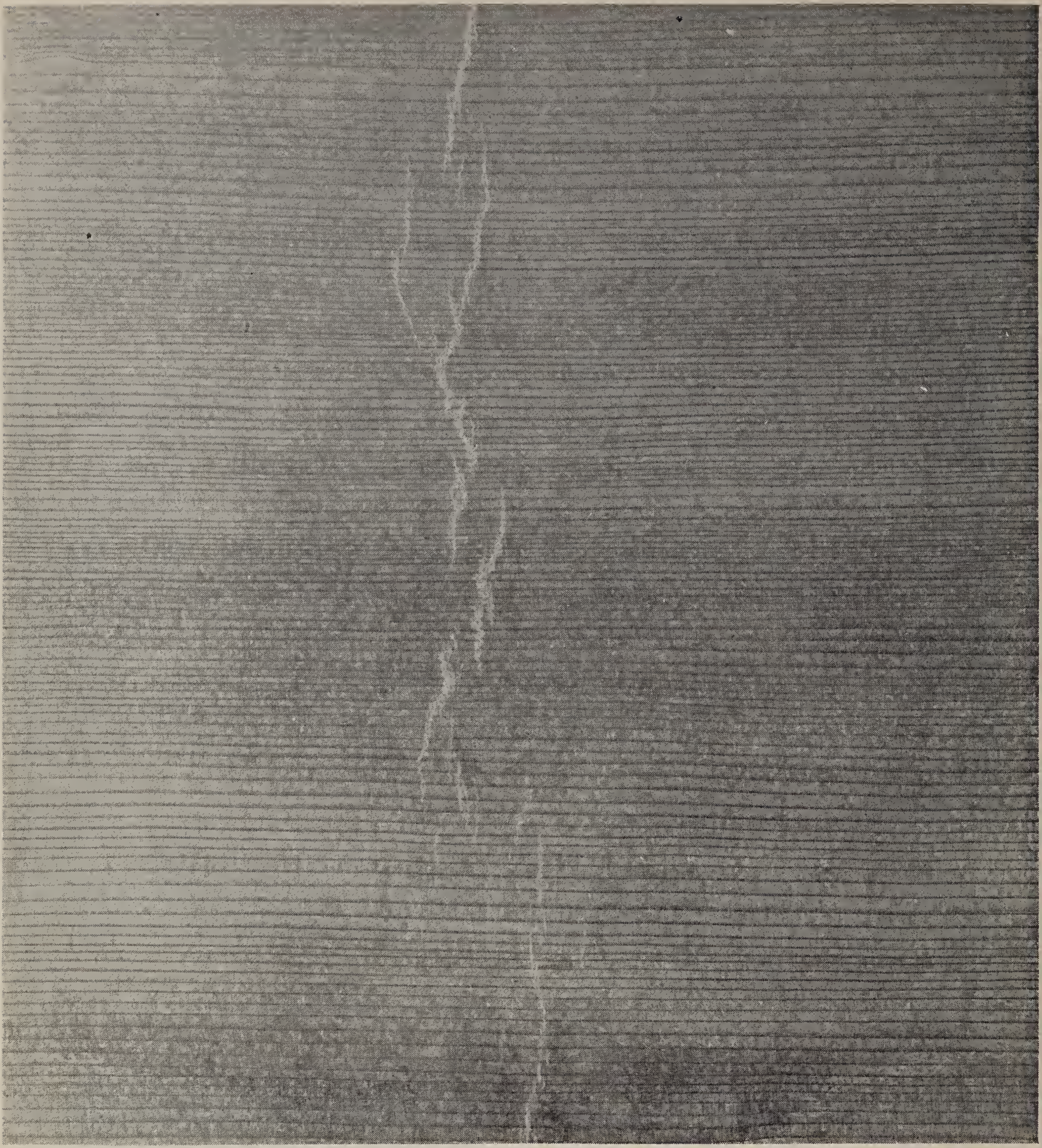

Figure 2–14.—Pronounced compression failure.

one thirty-second inch wide; a medium shake is between one thirty-second and one-eighth inch wide; an open shake is more than one-eighth inch wide; a through shake extends through the piece from one surface to another.

Depending on their size and the size of the piece of lumber, checks, splits, and shakes may seriously weaken wood members in resistance to longitudinal shear (sec. 4.2).

2.35. Compression Failures.—Compression failures should not be confused with compression wood (sec. 2.33). Excessive bending of standing trees from wind or snow, felling trees across boulders, logs, or irregularities in the ground,

or the rough handling of logs or lumber may produce excessive compression stresses along the grain which cause minute compression failures. The deformation of the fibers so caused ranges from well-defined buckling visible to the unaided eye as wrinkles across the face of a piece to slight crinkling of the fiber walls visible only with a high-power microscope.

Compression failures can best be seen by tilting a piece of wood back and forth under light from a direct source, such as a window or an electric bulb. A concentrated light beam such as a spotlight is best. Figure 2–14 shows how compression failures appear when viewed in this manner. Compression failures may be extremely weakening, especially on the tension side of a beam, or may cause lumber to break abruptly across the grain when roughly handled.

2.36. Pitch Streaks, Pitch Pockets, Bark Pockets.—Pitch streaks are well-defined infiltrations of resin in the fibers in the form of streaks. They normally occur only in pine, Douglas-fir, spruce, tamarack, and larch. As found in the better grades of lumber, practically all are small. They are chiefly objectionable because, especially in warm weather, pitch may exude.

Pitch pockets are well-defined openings extending parallel to the annual rings and containing more or less free resin and, occasionally, bark. Like pitch streaks, they occur mainly in pine, Douglas-fir, spruce, tamarack, and larch. They may weaken small members and resin may exude from them, especially when the wood becomes warm.

A bark pocket is a patch of bark partially or wholly enclosed in the wood. There is usually some slight separation, or at least a lack of cohesion, of the wood substance that has a definite weakening effect on thin material.

2.37. Burls.—A burl is a wartlike excrescence on a tree trunk with greatly distorted grain. It contains the dark piths of one to many buds which rarely develop. Somewhat similar distorted grain may form over the end of a broken branch embedded in the trunk by subsequent growth of annual rings. In thick timbers, it is frequently a sign that a knot is embedded within the timber. Burls are usually objectionable because they cause local distortion of grain. They provide attractive patterns in some veneers.

2.38. Wane.—Wane is defined as bark, or lack of wood or bark, from any cause, on any edge or corner of a piece of wood. Its importance lies chiefly in structural parts where cross section of the member or bearing area is affected. Figure 2–15 illustrates wane on a chord of a roof truss at a critical bearing area of the chord.

2.39. Stains and Decays.[2]

2.390. General.—All forms of decay, and many kinds of stains as well, are caused by fungi that grow in the wood. Fungi are plants, made up of fine threads (hyphae) invisible to the naked eye unless they are massed or matted together. A mass of hyphae is called mycelium. Figure 2–16 shows mycelium on oak. Fungi produce large numbers of microscopic spores, which are carried by air currents or insects and act like seeds in starting new infections on susceptible wood. The hyphae may grow into sound wood from other infected wood or from soil. Fungi will not grow in wood with a moisture content of less than 20 percent, and rapid decay takes place only at a moisture content of about 40 percent or above; however, the important fungi also need air and will not attack submerged logs or lumber.

Decay fungi soften wood and destroy or greatly weaken it. Staining fungi are generally limited to sapwood, do not soften the wood, and have little effect on most strength properties.

2.391. Stains.—Sap stain is not a stage of decay. It is due to entirely different fungi, which attack the stored food in the sapwood rather than the cell walls. It is nevertheless desirable to recognize stains, if only to avoid confusing them with decay.

The fungus-caused stains that will not surface off are of course objectionable for any members that are to have a natural finish. Furthermore, heavy stain may mean some reduction of shock resistance either by the staining fungus itself or by decay fungi which may develop under conditions that permit stain and which are difficult to detect in stained wood. For this reason heavily stained material should be discriminated against for members that are to be heavily stressed.

[2] The material in this chapter pertaining to decay was prepared in cooperation with the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, which is maintained at Madison, Wisconsin, in cooperation with the Forest Products Laboratory.

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FIGURE 2-15.—Roof truss of a prefabricated house containing wane at critical bearing area of lower chord. Bearing area is eccentric and critically reduced. Lower chord also badly blue stained.

2.3910. Blue Stain.—Blue stain occurs mainly in the sapwood of logs and lumber *(2-4)*, but is found in the heartwood of some coniferous trees, especially spruce. The color is predominantly bluish gray, although bluish-brown shades are found in hardwoods. If the stain is allowed to progress unhindered, the entire sapwood may become blue gray or even black. Severe blue stain may reduce toughness as much as 30 percent and affect other strength properties. Often decay is present also, as it is favored by conditions that produce stain.

2.3911. Brown Stain in Pines.—Two types of light to dark brown stain are often found, most commonly in pines. One is caused by a fungus and the other is a chemical stain that occurs during seasoning. Neither is associated with any significant change in the structure or hardness of the wood.

2.3912. Mineral Stains.—So-called mineral stains and streaks are common in hardwoods. Reddish- to grayish-brown colors, often with a definite tinge of green, are common in sweetgum, birch, and maple. In yellow-poplar, a variety of colors such as red, purple, yellow, lavender, green, and black are found. Brownish mineral stains in yellow-poplar are sometimes confused with decay. They differ from decay discolorations, however, in that when they occur in streaks they form the border of the stain and tend to contrast more sharply with the surrounding normal wood. Moreover, wood with even the darkest-colored mineral stain is not softened.

The bluish-black stain due to reaction of iron with the tannic acid of the wood is a familiar and harmless phenomenon.

2.392. Decay.—This discussion is concerned primarily with decay that may be in the wood

FIGURE 2-16.—Mycelium on oak and characteristic cracking of typical brown rot.

at the time it goes into construction, and with which the builder should be familiar in order to avoid putting decayed material into the house. Conditions affecting development of decay in houses after construction are discussed in section 6.1.

Decay fungi weaken wood by attacking the cell walls. By the time the decay has reached the stage of definite softening, strength is much reduced.

All species are subject to heart rot in living trees, despite the fact that the heartwood of many of them is much more resistant than the sapwood after the trees are felled.

It is usually a simple matter to recognize well-advanced rot or typical decay where the changes in wood structure are caused by prolonged action of the wood-destroying fungus. The early stages of decay are, however, far from easy to recognize. In some cases detection is practically impossible without examination of the wood under a microscope.

Incipient decay usually appears as a discoloration, in some cases pronounced, in other so faint as to be practically invisible. It rarely ends abruptly or evenly, but usually fades out in one or more irregular streaks. Such streaks usually extend not more than 3 or 4 feet, measured along the grain of the wood, beyond the typical decay. In softwoods the discoloration due to decay as observed on a cross section may be distinguished from the normally darker bands of heartwood by observing whether or not the darkening follows closely a definite group of annual rings. If so, the color variation is probably normal. If, on the other hand, the discoloration pattern is independent of the ring pattern, the color change may be a symptom of decay.

Incipient decay is most easily recognizable when the lumber is green, because the discolorations are more intense than after the wood has been seasoned or exposed to the light for some time. In the original piece it is ordinarily connected at one end with well-developed and recognizable decay. A drastic rejection policy at the sawmill is therefore the most effective safeguard. As a general rule, an allowance should be made of 2 feet along the grain beyond the last visible evidence of incipient decay, while across the grain an allowance of 2 or 3 inches is sufficient.

In inspection at later stages of manufacture, safe judgment depends first on thorough acquaintance with the appearance of normal wood of the species inspected. No known test can be used as a substitute for expert knowledge of a species acquired through experience.

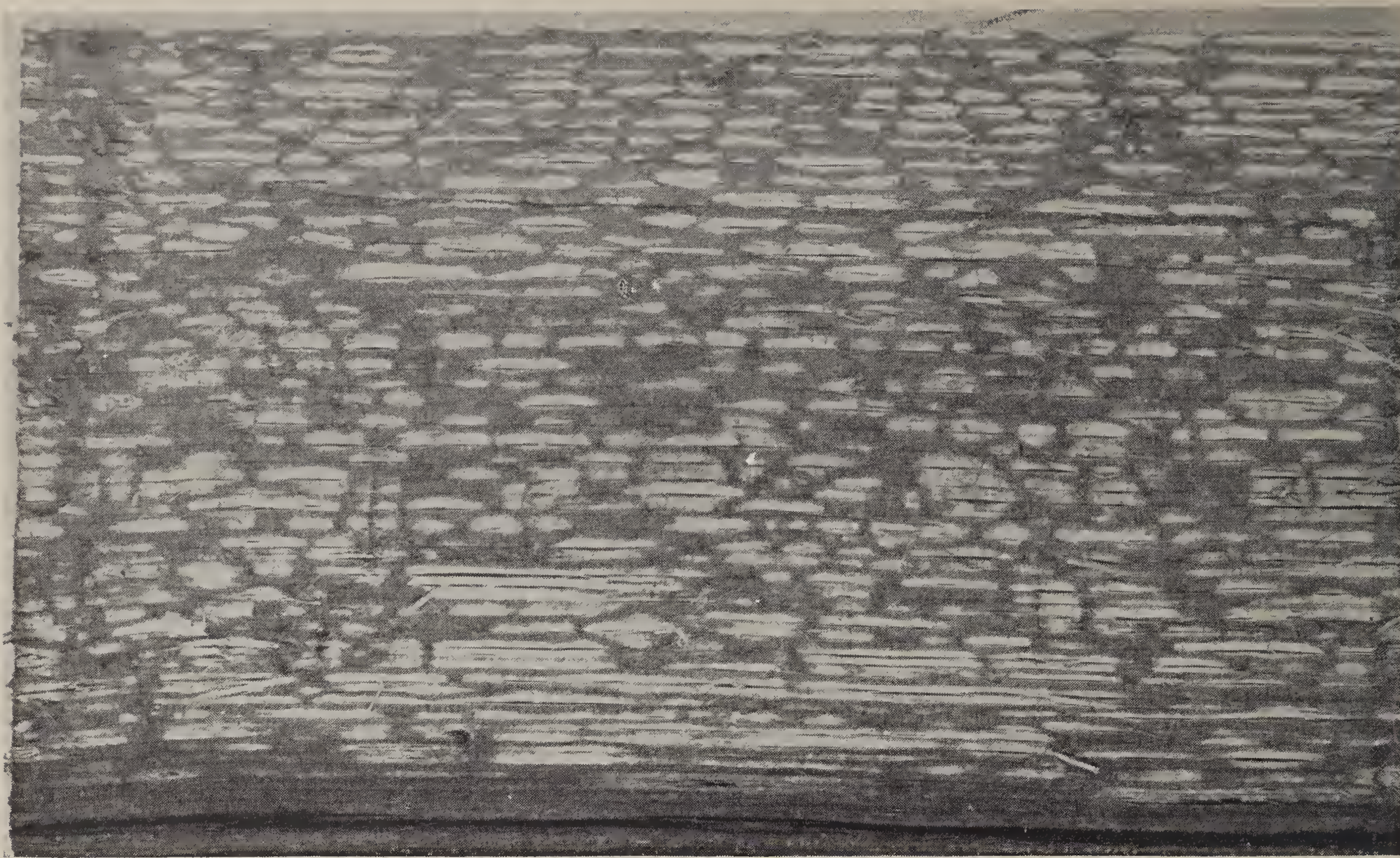

FIGURE 2–17.—White pocket rot.

2.3920. Types of Decay.—The classification of decays into white rot and brown rot is sometimes made on the basis of the ability of fungi causing the white rots to destroy lignin or the coloring matter of the wood, and of brown rot fungi to utilize more cellulose than lignin. A typical brown rot is shown in figure 2–16. This color classification does not hold for the incipient stages, in which some white rots are actually darker than the brown ones. Such classifications as stringy, cubical, or crumbly also are based on late stages of rot and have no interest to the builder. The classification of "dry rot" sometimes used is meaningless, since all wood must be moist while actively decaying, and all dry out about equally when deprived of moisture. The one type of rot than differs at all importantly from others is pocket rot, in which small limited areas are eaten out of the wood, but the wood between pockets is often firm and the timber may retain considerable strength. This is true, for example, in pecky rot of baldcypress, which does not continue to spread after the wood is dry. Pecky cypress is successfully used in places of high decay hazard if the pockets are not too numerous and weakening.

2.3921. Decay Occurring in Standing Softwood Trees.—The most common decay found in the heartwood of living coniferous trees is a white pocket rot readily recognized in its typical stage by the fact that the heartwood is honeycombed with small white pockets in which the wood is reduced to a soft fibrous mass, the pockets being separated by firm and apparently sound wood. Figure 2–17 shows typical decay of this character. The incipient stage of this decay causes no or only slight discoloration in the cedars, and varies from pink to red brown in pines, light gray to brown in spruce, and reddish or olive purple to brown in Douglas-fir.

Several fungi cause a reddish-brown crumbly rot in which the wood ultimately breaks into cubical fragments. The incipient decay may be accompanied by an extremely faint yellow or brown discoloration, very difficult to detect. In some cases the strength of the wood is considerably reduced even in the very early incipient stage.

There are, of course, discolorations that do not indicate decay infection, some of which are already described in section 2.391. These are often more conspicuous than the colors of in-

cipient decays. The reddish color commonly seen in Sitka spruce heartwood just next to the sapwood is an example of this. Most pure reds or reddish colors without brown or purple tinges are not connected with decay, especially if uniform over large surfaces. Especially in Douglas-fir and Western redcedar, light-colored zones in heartwood closely restricted to particular growth rings or zones of growth rings, are usually included sapwood due to failure of sapwood to complete its change to heartwood, and indicate not decay but perhaps greater susceptibility to infections that occur after construction. Compression wood is discussed in section 2.33.

2.3922. Decay Occurring in Standing Hardwood Trees.—In the hardwoods the very early incipient stages of decay are difficult to detect. In the freshly cut wood the infected areas frequently have a water-soaked appearance, but on drying only a very slight browning may indicate incipient decay. Any abnormal shade of brown, and yellow brown, greenish brown, and grayish brown may indicate decay. Some fungi change the color of the wood to cream or some shade of light straw to lemon yellow, commonly giving a bleached appearance to the wood.

Many fungi cause white pocket rots in hardwoods and others cause a brown crumbly rot (fig. 2–16). While the typical stages of these rots are readily recognized there is little known about the distinctive differences in the incipient stages.

Other fungi cause a white rot in which the entire heartwood becomes white or light straw colored. The decayed wood may or may not be interspersed with orange to black lines commonly called zone lines. In sweetgum, "figure" is not a stage of decay and does not indicate weakness.

2.3923. Detection of Incipient Decay.—It is a simple matter to recognize advanced or typical decay (fig. 2–16). But recognition of early or incipient decay is a much more difficult matter, and in some cases is practically impossible without microscopical examination of the wood. Nevertheless, there are discolorations and certain other characteristics produced by such decay that, with a little experience, can be relied upon ordinarily to denote the presence of incipient decay and to distinguish it from the harmless discoloration. The following criteria are offered as a guide in this respect. No instructions can be followed very successfully without thorough acquaintance with the normal color variations in the wood of the particular species.

2.39230. General Characteristics of Incipient Decay.

Abnormal Color:

(*a*) Any discoloration extending from zones of obvious decay indicates infection.

(*b*) Areas in which the color of the wood is some shade of brown not in the ordinary range of brown for the normal wood of the species may be infected. Shades of brown caused by decay are variable; in addition to what might be called "pure" brown, such shades as yellow brown, greenish brown, and grayish brown are common in hardwoods. In coniferous woods, distinctly reddish shades of brown are also prevalent, and in some species as in Douglas-fir the earliest decay discoloration is often a shade of purple. In some cases, the decay fungus soon bleaches the wood to a cream, straw, or yellow color.

(*c*) Aside from the color itself, an abnormal mottled appearance of the wood often indicates decay.

(*d*) If a discoloration is limited to certain growth rings it is not so likely to be decay as when it spreads across the rings.

(*e*) Decayed wood commonly has a duller color than normal wood, and is sometimes described as having a "dead appearance."

(*f*) Some decays, more commonly in hardwoods than coniferous woods, produce what are known as zone lines. These are very narrow black, orange, or yellow lines that tend to run somewhat in the direction of the grain. They are often most prevalent at or near the border of the most conspicuously discolored areas. Sometimes they are associated with very little general discoloration, but their presence is certain evidence of decay.

Softness and Brashness: Abnormally soft or brash wood should be suspected of decay even if no abnormal color can be detected.

Roughness of Surface: In some cases wood containing even incipient decay does not plane so smoothly as sound wood. The surface of veneer cut from rotted wood, even if only in the incipient stage of decay, is almost always rough.

Pitting of the Wood: Many decays produce few to numerous small pits or pockets in the

wood before or instead of any general destruction. Or, instead of being pitted, the infected zones may simply contain small spots that are softer and more intensely discolored than the intervening wood. In either case, the wood should be rejected.

2.393. Control of Decay.—A prime essential in preventing decay between felling of the tree and use of the lumber is to get the wood air dry as rapidly as possible without excessive warping or checking, and to keep it dry. Decay fungi cannot develop in wood that has a moisture content of 20 percent or less. Logs cut in seasons when the temperature is higher than about 40° F. should be sawed as soon as is practicable. The freshly sawed lumber should be either kiln dried or dried in accordance with good air-seasoning practice (ch. 9), and thereafter should be protected from rain or other sources of moisture until used. Storage directly on the ground should be particularly avoided.

Logs cannot, of course, always be utilized promptly, nor can lumber always be air dried rapidly. In either instance a large measure of temporary protection can be inexpensively provided by treating the surfaces of the wood with water solutions of appropriate toxic chemicals. Organic mercurial and phenolic chemicals are marketed for the control of blue stain in both logs and lumber, and the same ones are effective against decay for limited periods. Directions for using them are provided by the distributors. Water storage is often employed for logs.

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FACTORS AFFECTING THE USE OF WOOD IN HOUSING

3.0. GENERAL.—As with all materials, certain characteristics of wood govern its utility in whatever form it is used, whether as lumber, plywood, laminated wood, fibrous sheets more or less plastic in character, or even combinations of any of these with one another or with metals. The characteristics of lumber and plywood are reasonably well established; those of new materials as yet are to a greater or lesser degree being tested and evaluated by their performance, although their use is developing. In whatever form it appears, however, wood has certain well-defined characteristics. Fundamental to an understanding of these characteristics are such factors affecting its use as weight, affinity for moisture, and resistance to insects, fire, weathering, and decay. A major objective of research which has developed modern plywoods, laminated wood, the various wood and paper plastics, and the so-called "sandwich" materials is to broaden the utility of wood by improving its strength, decay resistance, resistance to shrinking and swelling, and other characteristics.

3.1. LUMBER.—Lumber is broadly defined as the product of the saw and planing mill not further manufactured than by sawing, resawing, and passing through a standard planing machine, crosscut to length, and matched.

3.10. Plain and Quarter-sawed.—Lumber as cut at the sawmill falls broadly into two types. These are known as plain-sawed or quarter-sawed lumber in hardwoods. Softwood lumber comparable to quarter-sawed hardwood is commonly called edge-grained or vertical-grained, and plain-sawed softwood lumber is known as flat-grained. Quarter-sawed or edge-grain lumber is produced by sawing the log along approximately radial lines. Plain-sawed or flat-grained lumber is obtained when the log is sawed lengthwise approximately tangent to the annual rings. The bulk of the lumber produced is plain-sawed or flat-grain. Figure 3–1 shows examples of plain-sawed (flat-grain) and quartersawed (edge-grain) lumber with relation to the manner of cutting it from the log.

Quarter-sawed or edge-grain lumber shrinks and swells less in width and twists, cups, surface checks, and case-hardens less in seasoning than does plain-sawed or flat-grain lumber. For this reason, quarter-sawed or edge-grain flooring is usually preferred to avoid undue opening between boards when it shrinks or cupping and crushing of the edges when it swells. Softwood edge-grain flooring wears more evenly and the grain does not raise or loosen as in flat-grain stock. Softwood flooring is usually considered to be edge-grained if the slope of the annual rings at the top surface is at an angle of 45° or more with it. Flat-grain or plain-sawed lumber is cheaper to produce and does not "collapse" so easily in drying in species subject to this particular defect, such as Western redcedar, redwood, and swamp oak. The knots in it, moreover, are round or oval instead of long and spike-shaped.

3.11. Grain.—The term "grain" is used rather loosely in connection with lumber. It is used in referring to (a) the annual rings; (b) the direction in which the fibers run, as straight, spiral, interlocked, curly, and wavy grain; and (c) the relative size of the pores and the fibers, as open and close grain. For the sake of clearness, the annual rings should be referred to as such, except with respect to the terms "edge grain," "vertical grain," and "flat grain," the meanings of which are thoroughly established; and (except as just stated) the use of the term "grain" should be confined to the direction of the fibers, as in straight, spiral, wavy, and interlocked grain. The term "texture" should be used to express the relative size of the pores and fibers or the relative amounts of springwood and summerwood, as "coarse" or "fine" texture, "even" or "uneven" texture.

3.2. PLYWOOD.—Plywood is usually made of an odd number of thin plies (veneers) glued together so that the grain of each ply is at right

angles to that of the adjacent ply or plies. In three-ply plywood the outside plies are termed "faces" or "face and back" and the center ply is the core. In the panels with five plies, the center ply is the core and the inner plies, the grain of which is usually at right angles to the faces and the core, are called cross-bands. For plywood used in house construction, the veneer usually ranges from one-sixteenth to three-sixteenths inch in thickness.

The chief advantages of plywood as compared with solid wood are its more nearly equal strength properties along the length and width of the panel, greater resistance to checking and splitting, very small change in width and length with changes in moisture content, and the fact that it can be produced in much wider sizes than solid wood. These advantages are obtained by alternating the direction of the grain in the successive plies.

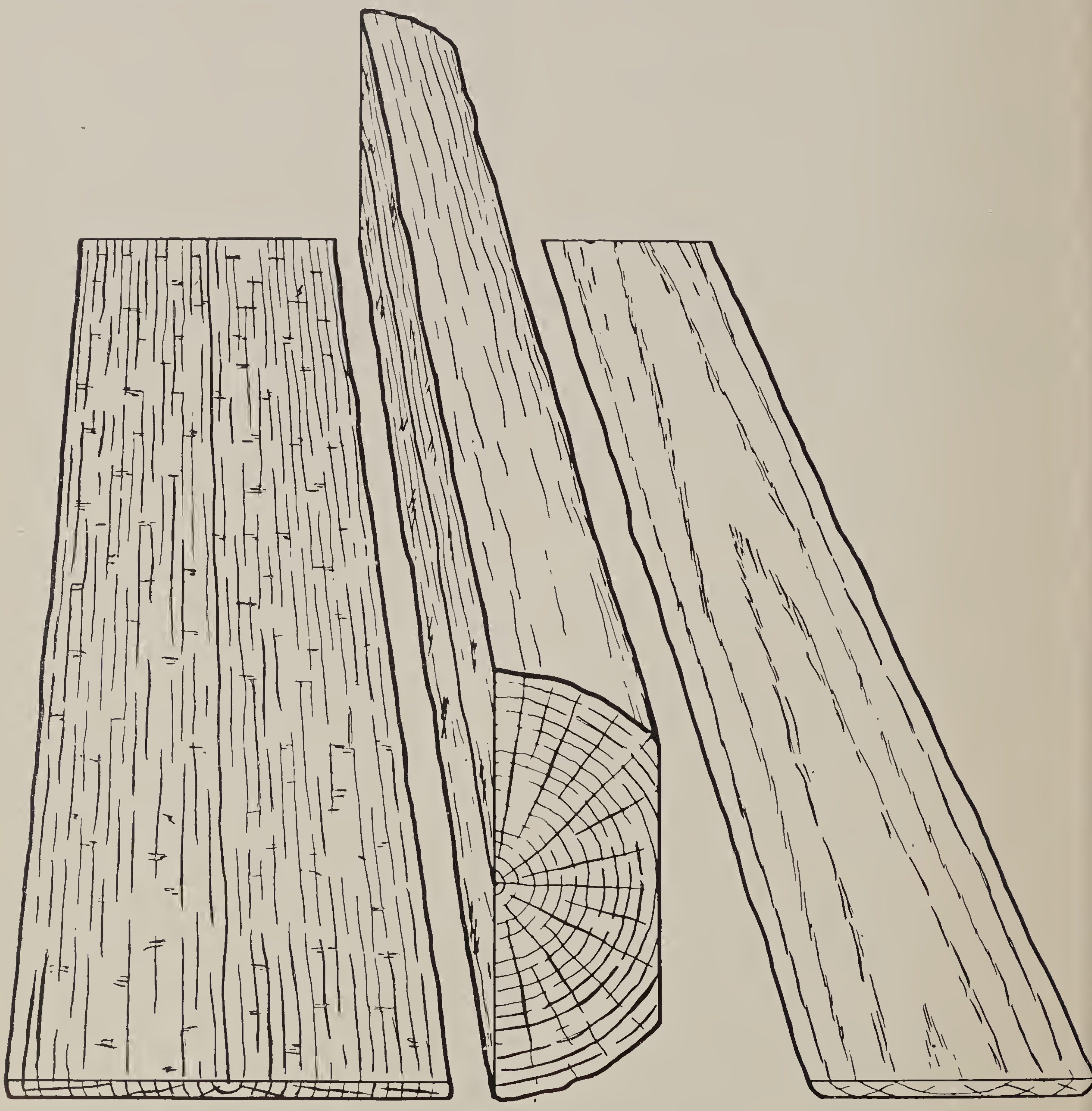

FIGURE 3-1.—Left, quarter-sawed, and right, plain-sawed boards cut from log.

The tendency of crossbanded products to warp as the result of stresses set up from shrinking and swelling with moisture content changes is largely eliminated by balanced construction. This construction consists of arranging the plies in pairs about the core or central ply, so that for each ply there is an opposite, similar, and parallel ply. Matching the plies involves consideration of (1) thickness, (2) kind of wood with particular reference to shrinkage and density, (3) moisture content at the time of gluing, and (4) angle or relative direction of the grain.

3.3. LAMINATED WOOD.—Laminated wood may be defined as wood built up of plies or laminations that have been joined either with glue or with mechanical fastenings. The term is most frequently applied where the laminations are too thick to be classified as veneer and when the grain of all laminations is generally parallel. Members made of laminated wood may be used with the width of the laminations either vertical or horizontal. Perhaps the most common example of the use of laminated wood in conventional house construction is the basement girder carrying floor joists and consisting of several 2 by 10's set on edge and spiked together.

Horizontally laminated members having laminations bolted, screwed, or nailed are very inefficient and should not be used. Glued laminated members with laminations either horizontal or vertical are as strong and stiff as solid members of the same quality provided the laminations are properly joined with a suitable glue. The strength of laminated members is covered in more detail in section 5.5.

The glue joints in a laminated member must not only be as strong as the wood, but must be of such character as to retain their strength under the conditions in which the member is used. Outdoor use, in which the member is subjected to extreme changes in temperature and relative humidity and perhaps to more or less exposure to free water, requires a glue that will retain its strength under these conditions. Indoor use, on the other hand, does not usually involve such rigorous conditions, and a somewhat wider range of glue types may be used with assurance of satisfactory service (sec. 10.1).

The use of laminated wood offers certain advantages over the use of solid wood for structural members:

(1) Laminated members can be made in any desired size, whereas the larger sizes of solid wood are becoming more and more difficult to procure. Larger cross sections may be obtained by the addition of laminations and by edge gluing two or more pieces to provide wider laminations. Where the length of lumber available is insufficient to provide laminations of the required length, several lengths of lumber may be jointed and glued. Such laminated members will be somewhat weaker than those without end joints and otherwise of equal quality. The reduction in strength will depend upon the type, number, and placement of the joints.

(2) Since the parts of a laminated member are of relatively small size, they may be more readily seasoned than large solid pieces without checking and other seasoning degrade. Further, they may be dried to a moisture content approximating the conditions of use with a resultant decrease in troubles in the structure resulting from shrinkage. As a result of the lower moisture content, some advantage may be gained in allowable stresses.

(3) The judicious use of high-quality material in the more highly stressed regions of a laminated member permits the use of the allowable design stresses appropriate to this material even though material of relatively low quality is used in the remainder of the member.

(4) The thinness of the component laminations permits them to be bent to simple curvatures of relatively short radius, so that a laminated member of relatively large section may incorporate curvatures which would be impossible with a solid member of comparable size. Distinctive architectural effects are thus possible through the use of curved laminated members.

(5) Where the member is of sufficient size and length to make it desirable, laminations can be tapered off to permit the cross sections to conform to the loads or bending moments at the various points.

Members made of laminated wood can be used in place of solid wood at any point in a prefabricated house. Production costs are generally somewhat higher than for solid straight

members of comparable size. Their use, therefore, will probably be limited to special applications. For example, they are adaptable to arch construction, where solid wood is more difficult to fabricate. They can also be used where it is desirable to have the finished member as nearly as possible at the moisture content expected in service so as to eliminate or reduce the effects of shrinkage after the member has been put into the completed structure.

3.4. MODIFIED FORMS OF WOOD.

3.40. General.—Various public and private research organizations in recent years have developed new forms of wood in an effort to modify for specific use conditions the properties of normal wood. The principal objectives of this research have been to make of wood a material less subject to dimensional changes, such as are caused by shrinking and swelling with changes in moisture content, and to obtain a material with more uniform strength properties in all directions. Research has also been devoted to finding ways of utilizing sawdust, shavings, and other wastes of the woodworking industries. The resultant products range from plywoods surfaced with special plastic materials to wood-fiber boards made by much the same pulping processes as are used in the paper industry and compressed in presses to the desired density. While some of these products are now extensively used in prefabricated housing, others are still in the experimental stage of their development.

3.41. Specialty Plywoods.

3.410. Resin-impregnated Paper-faced Plywood.—Several types of plywood faced with resin-impregnated paper have been produced in recent years. The face material used on these panels generally consists of one or more sheets of paper impregnated with 25 to 50 percent of thermosetting, phenolic-type resin. The paper-plastic material, when properly molded to the surface of the plywood, forms an integral part of the panel and cannot be peeled off.

One such type of faced paneling consists of Douglas-fir plywood faced with a dark brown paper plastic that gives it the appearance of a hardboard panel. The purpose of the facing material is to prevent surface checking of the plywood, to mask the grain of the wood, and to provide a readily paintable surface.

Another type of faced panel consists of Douglas-fir faced with a dense, brittle paper plastic, the chief quality of which is its high resistance to the passage of moisture. It also provides a smooth, abrasion-resistant surface on the wood. A variety of dark colors is possible. Panels of this type have found peacetime uses as drainboards and table tops. Hardwood plywood panels faced with this type of paper plastic have also been produced in limited quantities for use where such special properties as low water absorption and abrasion resistance are useful.

At present there are no generally accepted commercial standards for these panels. Before the panels can be generally recommended, more data are needed on durability, paintability, the effect of the relatively moistureproof plastic face on vapor transmission, and high moisture condensation problems of inside walls.

These new types of panels should not be considered substitutes for conventional building materials. At present they are more expensive than plywood and will normally find use only where their improved properties are considered especially useful. There is great interest in the development of improved panels, generally with a specific end use in mind. As new plastic-faced plywood panels appear, their special properties should be carefully considered with respect to the particular use contemplated.

3.411. Other Special Plywood Products.—The principle of plywood construction lends itself to many unusual combinations of wood. Flooring panels of considerable size are sometimes made, using relatively inferior grades of wood for the body of the panel, to which an excellent floor surface is bonded consisting of birch veneer or veneers of other hard species of wood, as well as vertical-grain Douglas-fir, in thicknesses of one-eighth inch or more. The purpose is to provide a floor with better wearing qualities than rotary-cut veneer offers.

A special type of Douglas-fir wall paneling material has recently been made from plywood that has a face of somewhat thicker veneer than the back. This face is scored to a depth of about one-sixteenth inch with many close grooves, oriented so as to run parallel to the grain direction of the face ply. This plywood is used on exterior walls with the scoring running vertically, either in full-sized panels or in

strip form applied as lap siding. It is also being used for interior walls. The scoring is said to be effective in breaking up the rather pronounced grain pattern of the Douglas-fir, in making the small face checks that sometimes occur on Douglas-fir less noticeable, and in making any dirt pattern that might develop less evident.

3.42. Wood-fiber Board Materials.—Various types of fibrous board materials have in recent years come into increasing use in housing. While their primary purpose in most cases has been to provide thermal insulation, some of these have gained a place in low-cost housing as semistructural or curtain-wall materials in interior partitions and ceilings. A few have been demonstrated to be suitable for exterior wall covers from the standpoint of durability under outdoor exposure. Some prefabricators make extensive use of these products.

In general, four types of fibrous materials are manufactured, rigid boards, semirigid sheets, flexible mats, and fill-type insulation. Of these, only the rigid boards generally are used in themselves for structural purposes. Some semirigid types, however, are finding structural application when used as the core material in a sandwich type of product with stiff faces. The flexible mats and fill-type materials are used only for insulation (sec. 8.112).

3.420. Rigid Boards.—Besides wood fiber, rigid board materials are made from waste paper, cork, bagasse, wheat straw, corn stalks, and screenings from paper mills. Their manufacture closely resembles that of paper. The wood fibers used for paper are also used for production of these boards. The wood chips are softened by mild chemical treatment or steaming under pressure and fiberized in attrition mills, or the untreated wood in the form of short logs or blocks is mechanically reduced to a fibrous condition in pulpwood grinders. These fibers, in a water suspension, are then run over a paper machine and reduced to a wet mat. This mat is compressed under rollers or in a hydraulic press and then finally dried in a dryer similar to those used to dry veneer. Depending upon the pressure exerted upon it by the press, a hard, smooth board with varying porosity is produced.

Rigid boards produced in this manner are known as homogeneous boards. Other types of rigid boards are of laminated construction—either several thin homogeneous boards pressed or glued together, or many sheets of paper laminated to form a board three-sixteenths inch thick or thicker. They are made in panels ranging in size from 4 by 6 feet to 12 by 12 feet. When used as curtain-wall materials, the larger sizes are frequently employed by manufacturers of so-called room-size sections or panels for walls, partitions, and ceilings. The builder of prefabricated houses should, when adopting such boards for structural purposes rather than purely as insulators, ascertain from a competent source the strength properties of the material—and those of the house panels he plans to make with it as well. The strength properties of such boards vary considerably (sec. 5.8). Some have, however, given satisfactory service in prefabricated and other types of housing. Their use in stressed-cover construction has not been fully tested as yet.

3.421. Other Fiber Materials.—The semirigid boards and flexible sheet materials are prepared in the fibrous condition in much the same way as the rigid boards. The flexible materials usually consist of a loosely aggregated mat covered on both sides with paper or fabric. The raw materials used in their manufacture include wood fibers, hair, grass, kapok, or mineral substance. Flexible insulators are usually called "blanket" or "batt" types of insulation (sec. 8.112).

Fill insulation consists of granulated, shredded, or powdered material either in bulk or in the form of batts. Various materials are used, including shredded vegetable fiber, gypsum, limestone or other rock, slag, charcoal, bark, sawdust, shavings, grain hulls, shredded paper, and diatomaceous earth.

3.43. Wood-base Plastics.—The word "plastic" has in recent years become a broad, generic term including many kinds of materials that can under certain conditions be molded to desired shapes. Under this loose definition, wood itself is a plastic material, since it can be softened by hot water or steam to a certain degree of moldability. True plastics, however, are in general materials that can, at some stage of their production, be pressed to given shapes without acquiring stresses that remain in the finished product and affect its strength or stability of form.

The most common plastics available today consist of synthetic resins with or without some filler material such as wood flour. Other widely used plastics are cellulose derivatives, such as cellulose nitrate and acetate, which are largely made from wood pulp. Common examples of such plastics are tool handles of various sorts, automobile steering wheels, washing machine agitators, and toys. Their nature, properties, and above all their cost, do not lend them to wide utility as housing materials.

Other materials which, in the nature of their manufacture, may be classed as plastics include some of the fibrous wallboards, especially those made by methods similar to those employed in paper manufacture (sec. 3.42). As yet, these materials find extensive use only in flat panel form for housing. It is possible, however, to mold them to curved shapes in hot presses by incorporating synthetic resins or some other binding material in the pulp base. Obviously, however, such treatments involve added expense, and the need for them is, at best, questionable.

Among materials that hold promise of ultimate usefulness in housing, although at present still in the experimental stage of their development, are a number of wood-base products (modified woods and paper-base laminates) that, because of their improved moldability, fall within the broad category of plastics. Among these are such nonproprietary products as impreg, compreg, staypak, staybwood, acetylated wood, papreg, and various commercial densified, stabilized, and resin-treated products.

Impreg and compreg are made of natural wood by fixing synthetic resin in the intimate cell-wall structure in such a manner that shrinking and swelling are markedly reduced. Impreg consists of wood so treated, usually in the form of thin sheets of veneer because the treatment is most satisfactorily applied to thin wood. Compreg consists of impreg sheets compressed together under heat prior to setting of the resin to form a board material of high density as well as improved dimensional stability.

Resin treatment also imparts a high degree of resistance to face checking and a significant decay and termite resistance to the wood. When the wood is appreciably compressed (compreg or semicompreg) the wood assumes a natural lustrous surface finish. Any cut surface can be given this finish by sanding with fine sandpaper, followed by buffing. Both impreg and compreg show their greatest potential use in housing in the form of thin surface plies over normal plywood because of their high cost in thick solid form. Because of the plasticizing action of the resin-forming chemicals on wood at elevated temperature prior to setting of the resin, the faces can be compressed significantly under a pressure that will not compress the core. In this way a combination of compressed faces on an uncompressed core can be made in a single assembly and compression operation. This type of material shows promise for use as exterior siding, interior paneling, built-in furniture, and flooring for houses, especially when species that normally are subject to face checking are used. In the latter application the faces can be compressed to such a degree that they have the desired hardness and abrasion resistance, even when normally unsuitable soft species are used. The treatment will also give a natural permanent finish that if scratched or marred can be restored by sanding and buffing. The extent to which these materials will be used will depend largely on finding means of reducing costs.

Staypak, an untreated compressed wood that is made under moisture content and temperature conditions that relieve the internal stresses and thus practically prevent springback under swelling conditions, is a potentially cheaper product than compreg, with quite similar properties. Unlike compreg, it can be made to advantage from solid wood. It is tougher than compreg, but is more susceptible to swelling and shrinking and attack by organisms. It has a natural finish like compreg when buffed. It might be sufficiently water-resistant for flooring and hence might be advantageously made from soft species with naturally unsuitable mechanical properties.

The cheapest means of imparting dimensional stability to wood thus far found is to heat it after drying to temperatures and for periods of time just insufficient to cause char. When this is done in a molten bath to eliminate oxygen, the product, staybwood, has lost a minimum amount in strength properties. Decay resistance as well as dimensional stability is imparted to the wood. Further work on gluability

and paintability is needed before the process should be applied to housing use. This treatment might prove suitable for window frames and window casings where dimensional stability and decay resistance are of importance and full strength is not needed.

The most effective means of stabilizing the dimensions of wood that has been found to date is to acetylate the wood by a vapor-phase treatment with acetic anhydride and pyridine. This treatment in its present form is applicable only to veneer. The process is unique in that it does not affect the appearance or reduce the toughness of the wood. Considerable decay resistance is imparted to the wood. The process should be slightly cheaper than resin treatment, but it is still too expensive for general use. Its chief potential use in housing would be for facing of plywood similar to the suggested applications for impreg and compreg.

Papreg is a resin-treated form of paper that offers most promise as a surfacing material for plywood. It, like impreg, is resistant to moisture and such hazards as decay, termite attack, and weathering. It is in commercial use as a plywood surfacing material (sec. 3.410) for such applications as sink counters and table tops and offers distinct possibilities of development for more extensive use on exterior plywood. In its present stage of commercial development, however, it is, like most other plastic materials, too expensive for other than specialty applications.

3.44. Sandwich Materials.—Among the new materials developed in recent years, so-called "sandwiches" consisting of unlike materials glued together to combine strength with light weight are among the most promising structural materials to appear. Originally conceived for use in military aircraft, they have been intensively developed for this purpose. Their application in other fields, including housing, requirements for which are in some respects less exacting, holds exceptional promise.

For use in aircraft, sandwich construction can be defined as any panel construction of three or more plies having thin, dense, high-strength faces separated by a relatively light-weight core capable of carrying sufficient shear stress to develop essentially the full strength of the faces.

Common face materials for aircraft applications include aluminum, plywood, fiber-reinforced plastic sheets, and steel. Core materials which have been used are balsa, firm sponge constructions of rubber, cellulose acetate or some other plastic, and networks of resin-impregnated paper or cloth resembling a honeycomb (commonly called honeycomb cores). The usual density of these core materials is from 6 to 10 pounds per cubic foot.

Adaptation of aircraft-type sandwich constructions to housing requirements, already begun, promises considerable evolution of these materials. The basic aircraft requirements are more rigid from the standpoint of strength and stiffness than are those for housing. Sandwiches for house construction, in particular, can utilize elements that are not so critical from the standpoint of weight. On the other hand, the cost factor is more important in housing than in aircraft. Many of the sandwiches devised for aircraft would be well suited to housing but for this element of cost.

There are, however, various less expensive materials than those employed in aircraft sandwich construction that are suitable for housing. Moreover, less costly fabrication techniques can be employed with these materials. Among core materials, those of the honeycomb type hold considerable promise. Faced with plywood (with or without plastic overlays), fiber-reinforced plastic, or aluminum, such core materials have experimentally produced satisfactory sandwich constructions. While still light enough to facilitate handling and shipping, these sandwich panels possess adequate strength, insulation value, stiffness, and other properties for use as load-bearing walls, floors, and roofs. Cores of such materials as sponge rubber and foamed plastics, on the other hand, offer little promise for house panels because of relatively high material costs.

Other types of sandwich constructions incorporate an insulating material, such as fiberboard, as the core, to which are glued faces of thin plywood or other rigid materials that contribute the necessary stiffness and strength to resist wind loads and racking forces. This type of sandwich has been relatively little explored, and data are lacking on the necessary design elements, such as face thickness, shear strength of core materials, and strength properties.

Besides fiberboards of the rigid type, insulation materials such as cellulose fiber mats and molded sawdust, as well as eggcrate constructions of wood strips and plywood honeycombs, have been tested in research. To date, however, they have either failed to pass preliminary tests or are basically too expensive.

3.5. SPECIFIC GRAVITY.

3.50. General.—Specific gravity is the ratio of the weight of a given volume of a substance to the weight of an equal volume of water. Since wood exists unaccompanied by water only when oven dried, the specific gravity of wood is sometimes taken as the ratio of the weight of the dry wood substance present in a given volume to that of an equal volume of water. Because the most nearly constant volume of wood is its green volume, which is not subject to shrinkage, specific gravity is often based on oven-dry weight and volume when green. Such a value is an index of the weight of dry wood substance present in a certain volume of green wood. Table 3–1 gives the average specific gravity values for various species of woods used in house construction on the basis of their oven-dry weight and volume when green.

TABLE 3–1.—*Average values of specific gravity, based on weight when oven-dry and volume when green, for various housing woods*

Species	Specific gravity	Species	Specific gravity
Hardwoods		*Softwoods*	
Ash, black	0.45	Baldcypress	0.43
Ash, commercial white [1]	.54	Douglas-fir (coast)	.45
Basswood, American	.33	Fir, noble	.35
Beech, American	.56	Fir, white	.35
Birch	.57	Hemlock, Western	.38
Chestnut, American	.40	Larch, Western	.48
Cottonwood, Eastern	.37	Pine, Eastern white	.34
Elm, American	.46	Pine, loblolly	.47
Elm, rock	.57	Pine, longleaf	.54
Hackberry	.49	Pine, ponderosa	.38
Magnolia, Southern	.46	Pine, red	.44
Maple, red	.49	Pine, shortleaf	.46
Maple, silver	.44	Pine, sugar	.35
Maple, sugar	.56	Pine, Western white	.36
Oak, commercial red [2]	.56	Redcedar, Western	.31
Oak, commercial white [3]	.59	Redwood	.38
Sweetgum	.44	Spruce, red, white, and Sitka	.36
Sycamore, American	.46	White-cedar, Northern	.29
Tupelo, black	.46	White-cedar, Port Orford	.40
Tupelo, water	.48	Yellow-cedar, Alaska	.42
Walnut, black	.51		
Yellow-poplar	.38		

[1] Includes white ash, green ash, and blue ash.
[2] Includes white oak, bur oak, swamp chestnut oak, and post oak.
[3] Includes Northern red oak, Southern red oak, laurel oak, water oak, swamp red oak, willow oak, and black oak.

Although the specific gravity value based on oven-dry weight and volume when green is a useful index of the properties of wood, it requires the measurement of the volume when green. For general purposes, the piece can be oven dried and its specific gravity calculated on the basis of oven-dry weight and oven-dry volume.

The specific gravity of a floating body, such as most woods are, can be determined by ascertaining the ratio of its volume below the water line to that of the whole piece. The determination of specific gravity by this method is done as follows:

1. Cut a piece of wood from the board to be tested, about 1 by 1 by 12 inches in dimension, the 12-inch dimension being along the grain.

2. Dry the piece for about 48 hours at from 212° to 221° F. This will remove practically all of the moisture.

3. Dress the piece so that the cross section is rectangular and uniform throughout the length, and trim it to exactly 10 inches in length. Mark off and number the length in inches.

4. Place the piece carefully in a tall glass container of water so that it floats in an upright position (fig. 3–2). Note the water line to which it sinks, quickly removing the piece and marking it. The position of the water line indicates the specific gravity of the piece on the basis of oven-dry weight and oven-dry volume. Thus, if the mark is halfway between 4 and 5, the specific gravity is 0.45, The whole operation must be performed quickly, because the oven-dry piece will begin to pick up moisture while it is being dressed, cut, and marked and when it is placed in the water.

3.6. MOISTURE CONTENT.

3.60. General.—All wood subjected to normal use conditions contains more or less moisture. The exact quantity depends upon the amount of seasoning the material has received and, more important from the standpoint of long-time use, the atmospheric and other conditions to which it is exposed.

Lumber cut from freshly felled trees contains varying amounts of moisture often called "sap." Sap is composed principally of water, with varying amounts of other materials in solution. This moisture exists in the wood in two forms, as bulk liquid, contained in the cell cavities, known as free water; and as absorbed or "im-

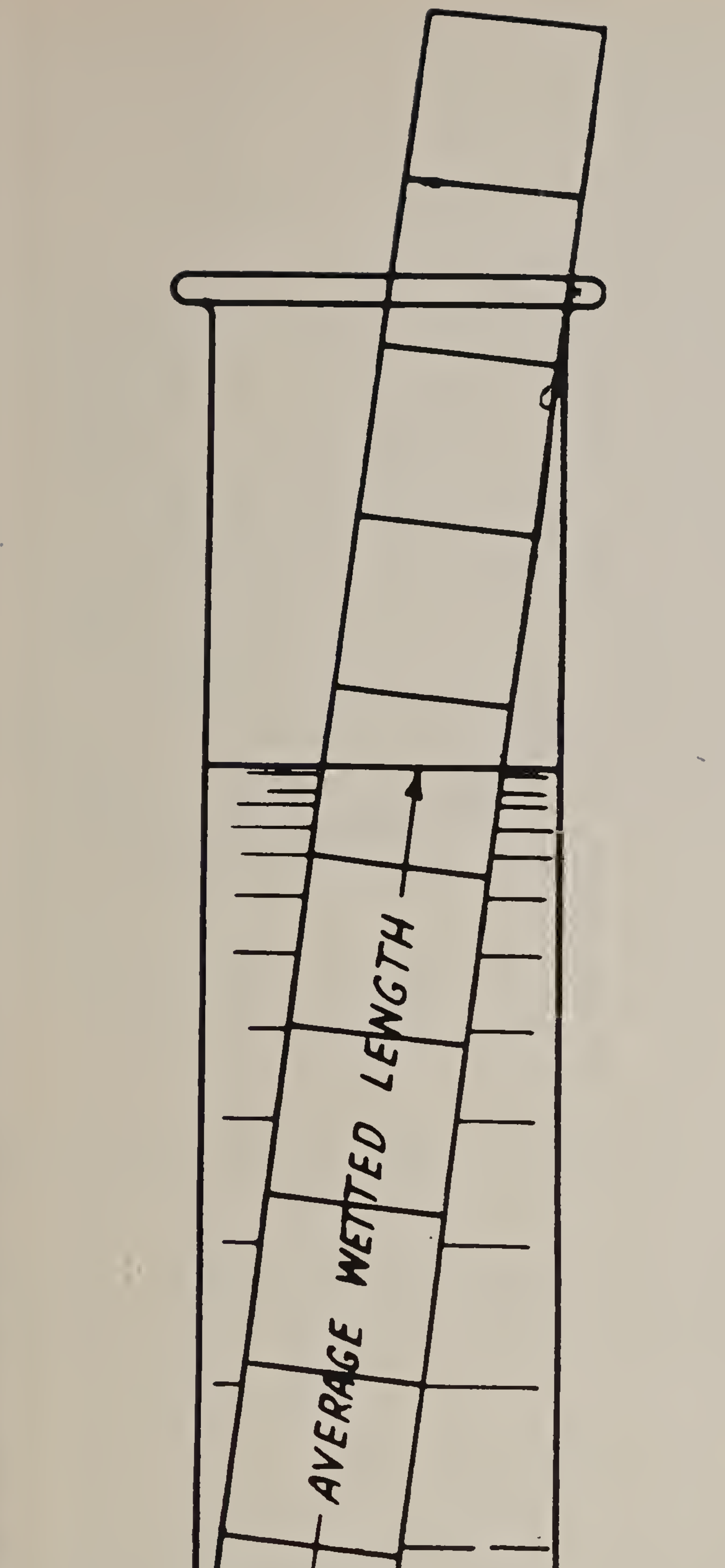

FIGURE 3–2.—Container suitable for making specific gravity tests on wood by the flotation method.

bibed" moisture held within the cell walls. Sapwood usually contains more moisture than the heartwood, the difference being more marked in softwoods than in hardwoods.

Freshly cut or unseasoned lumber is called "green," an indefinite term applied to lumber that has not been seasoned and therefore contains most of its original moisture. Green lumber may contain a weight of water considerably greater than its own dry weight, but usually the quantity held within it is much less.

As the wood dries, this free water is removed first from the outermost and progressively from the fibers further within the piece, until the cells are virtually empty of it. Only at that stage, called the fiber-saturation point (for most species considered to be about 30 percent moisture content), does the imbibed water within the cell walls begin to leave. As drying continues below the fiber-saturation point, the wood shrinks, again progressively from the outside layers inward. Green lumber exposed to the atmosphere dries until it reaches a condition in balance with that of the surrounding air. Its moisture content in this condition is called equilibrium moisture content. It varies with temperature and relative humidity, being affected more by relative humidity than by temperature (fig. 3–3). Between 60° and 0° F.,

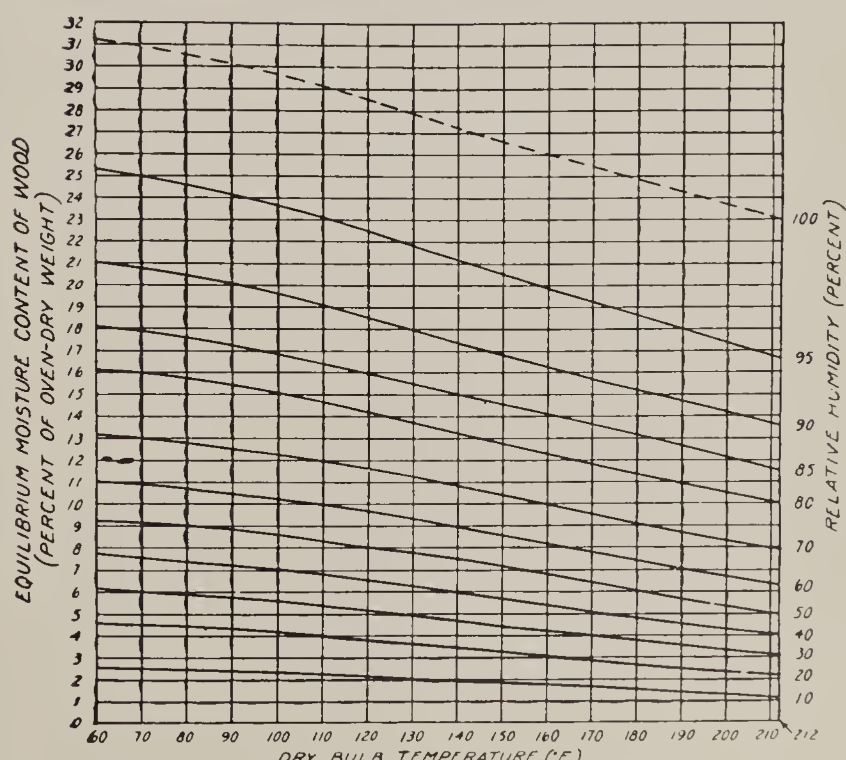

FIGURE 3–3.—Relation of dry-bulb temperature, relative humidity, and equilibrium moisture content of wood.

the equilibrium moisture content of wood at various relative humidities will change only 1 or 2 percent.

Normal daily temperature and relative humidity changes do not have any pronounced effect on the moisture content of wood. Changes over a more extended period of time, such as seasonal changes, cause its moisture content to change until again in equilibrium. Swelling and shrinking of the wood accompany this change (sec. 3.7).

The use of figure 3–3 in determining the equilibrium moisture content of wood is illustrated by the following example:

Example: Find the equilibrium moisture content of wood at a temperature of 110° F. and a relative humidity of 70 percent.

First, locate the vertical temperature line for 110° F. on the horizontal scale. Second, locate the intersection of this line with the 70 percent relative humidity curve extending from the right-hand vertical scale. The point on the left-hand scale horizontally opposite this point of intersection gives the reading desired, in this case 12 percent equilibrium moisture content.

Moisture content is usually expressed as a percentage of the weight of the oven-dry wood. If the moisture content of a green board is 150 percent, the moisture constitutes three-fifths of the total weight of the board. Moisture content is a relative term and does not give a measure of the absolute amount of water present unless the density of the wood is taken into consideration. An oak board at 20 percent moisture content, for example, contains more water than a spruce board of the same dimensions at the same moisture content because the oven-dry weight of the oak board is greater than that of the spruce board, hence more water is needed to make up 20 percent of its dry weight.

The trade terms "air-dry," "shipping-dry," and "kiln-dried" have no specific meaning with regard to moisture content. Air-dry lumber may have a moisture content ranging from 6 percent in the arid Southwest during the summer to 24 percent in parts of the Pacific Northwest during the winter. In general, the average moisture content of thoroughly air-dry lumber is about 12 to 15 percent. Lumber that is partially dried to reduce freight charges is known as "shipping-dry" and may have a moisture content of 30 percent or more. Kiln-dried lumber is commonly reduced to a moisture content of 4 to 12 percent depending on the requirements for its use, although kiln-dried softwood lumber in common grades is sometimes only partially seasoned to 15 to 22 percent moisture content.

3.61. Moisture Content Determination.—Two methods most commonly used to determine the amount of moisture in wood are the oven-drying and electrical methods. The oven-drying method is more exact and is applicable over a wider range of moisture content values, whereas electric moisture meters, although somewhat limited in range and accuracy, offer more rapid means of estimating moisture content without necessitating the cutting of samples from lumber.

3.610. Oven-drying Method.—Five steps are necessary for accurate moisture content determination of wood by the oven-drying method:

1. Select a representative board and cut a cross section about 1 inch long in the direction of the grain.
2. Immediately after sawing, remove all loose splinters and weigh the sample.
3. Put sample in an oven maintained at a temperature of 212° to 221° F. (100° to 105° C.) and dry until constant weight is attained.
4. Reweigh the sample to obtain the oven-dry weight.
5. Divide the loss in weight by the oven-dry weight and multiply the result by 100 to get the percentage of moisture in the original sample. Thus,

$$\textit{Percentage moisture} = \frac{(W-D)}{(D)} 100$$

where W is the original weight as found under 2 above and D is the oven-dry weight as found under 4 above.

First Step: If possible the sample should be taken at least 2 feet from one end of the piece. Wood gives off or takes on moisture more rapidly from the end grain than from side grain; as a result, there may be considerable difference between the moisture content at the end and elsewhere in a board. For this reason, a sample from within 2 feet of the end of a long board may not be representative.

Short pieces of wood dry out much more rapidly than longer ones. In order to reduce the time required for drying, therefore, the length of the sample in the direction of the

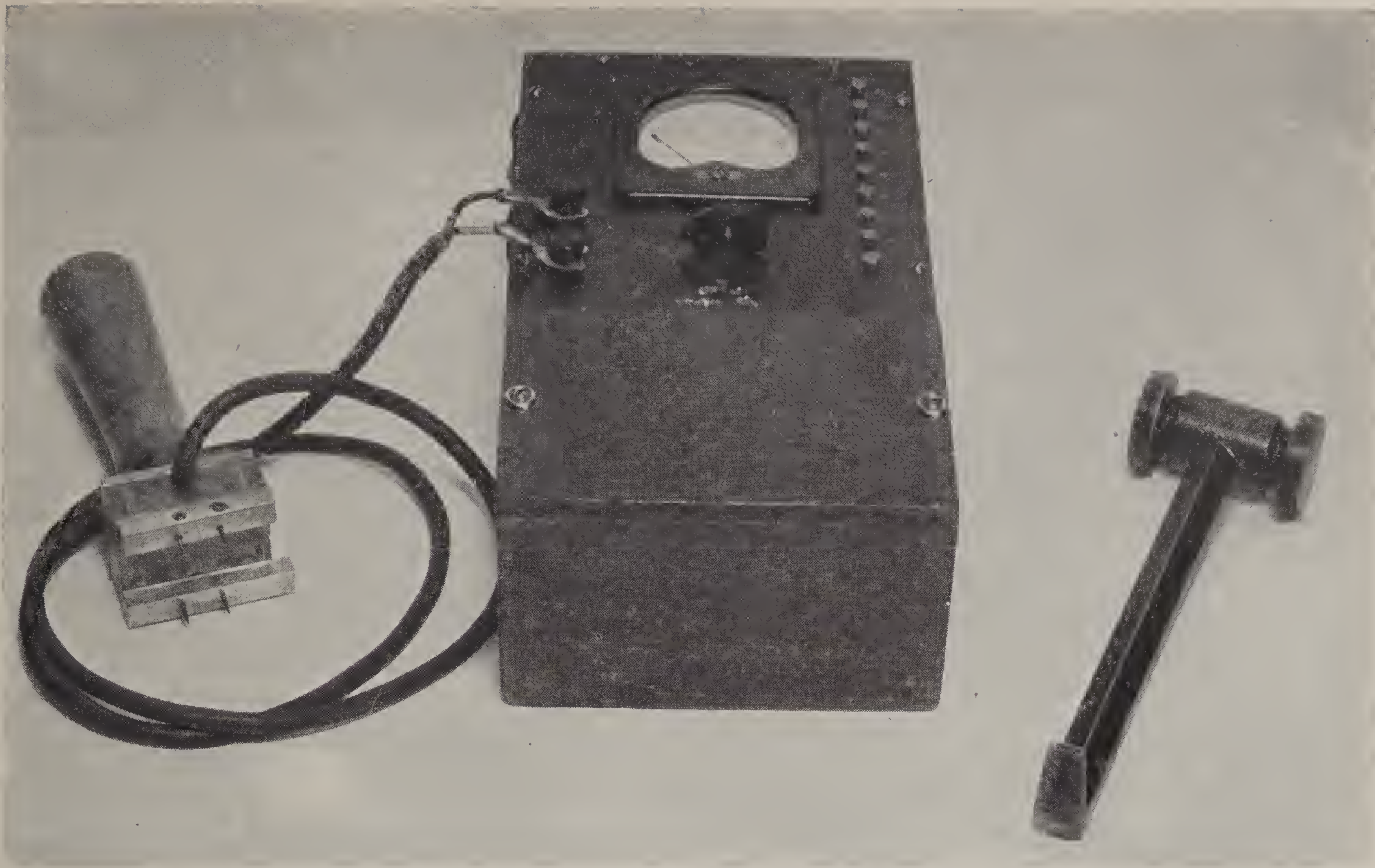

FIGURE 3-4.—Electric resistance-type moisture meter for determining the dryness of wood.

grain should usually be not more than 1 inch. With material 1 square inch or less in cross-sectional area, however, a sample more than 1 inch long is generally desirable, and the length in this case may be chosen so as to give the sample a volume of 2 or more cubic inches. The other dimensions may be equal to the cross section of the board from which the sample is taken.

Second Step: It is important that the weight be taken immediately after the sample is cut, for the material is subject to moisture changes on exposure to the air. The degree and rapidity of changes are dependent on the moisture content of the piece and the air conditions to which it is exposed. Where it is not possible to weigh the sample immediately, it may be wrapped in foil or waxed paper until it can be weighed.

In order to insure good results, the weights should be correct to within at least 0.50 percent of the dry weight of the sample.

The metric system of weights is convenient in making moisture determinations.

The kind of scales to be used and the size of the smallest graduation necessary to insure the specified accuracy will depend on the weight, and consequently the size, of the sample and kind of wood. Small spring postal scales reading to one-half ounce are not suitable for accurate weighing of small moisture samples.

Third Step: When placed in the oven for drying, the samples should be open-piled to allow free access of air to each piece. The oven should have some ventilation, thus allowing the evaporated moisture to escape. A thermometer should be provided by which the temperature can be ascertained at any time. Excessive temperatures or excessive periods in the drying oven will cause distillation of the wood, and erroneous results will be obtained. Ordinarily, in the case of low-density woods, 12 hours' oven drying is sufficient, while high-density woods may require 48 hours' oven drying, although samples containing considerable moisture should remain for a longer period than those containing less moisture.

Fourth Step: As in the case of the first weight taken, it is essential that the sample be weighed immediately after being removed from the oven.

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Fifth Step: A typical example of the computation necessary for determining the percentage of moisture is:

A 2 by 2 by 1-inch sample of air-dry Sitka spruce weighed 30.8 grams. The sample after oven-drying weighed 27.5 grams. Find the moisture content of the sample.

$$\text{Percentage moisture} = \frac{(30.8\text{-}27.5)}{27.5} \text{ X } 100 = \frac{330}{27.5} = 12.$$

3.611. Electrical Method.—Electric moisture meters (fig. 3–4) are extensively used for the determination of the moisture content of wood, and while they are simple to operate, some judgment and care is required in their use. They have an advantage over other methods for determining the moisture content of wood because of their convenience and speed, the time required to determine the amount of moisture in any piece of wood being only a few seconds. Two general types of instruments are available. One evaluates the moisture content by measuring the electrical resistance of the wood using direct current, and the other measuring the electrical capacity or power absorbed by the wood when associated with the circuit of a vacuum-tube oscillator.

3.612. Resistance-type Moisture Meters.—Below moisture content values of 25 to 30 percent, the electrical resistance of wood increases greatly as water is removed. By measuring the electrical resistance of the wood, its moisture content may be evaluated. Moisture meters of the resistance type are usually calibrated for a range in moisture content values of 7 to 25 percent, although several are calibrated from 7 to 60 percent moisture content. In the 7 to 25 percent moisture content range, the accuracy of resistance-type instruments, when properly calibrated and used for testing either relatively thin samples or thicker material that is known to be of uniform moisture content, is within approximately 1 percent of the correct moisture content in the majority of cases. Readings of moisture content above 25 percent will not be so accurate as those in the lower range, nor do they ordinarily need to be.

Electrical contact is generally made by driving four needle points into the wood to be tested so that the flow of current is parallel to the grain. The two points of like polarity are usually spaced one-half inch apart, and the points of unlike polarity about 1¼ inches apart in the direction of current flow. All the points are usually mounted in a block of insulating material and arranged so that they can be readily driven into the wood and withdrawn again after testing. Several different designs are available. Contact may also be made by clamping surface plates to the opposite faces of the specimen. The needle-point type of electrode is thought to be preferable to the surface-contact type in making resistance measurements where a drying moisture distribution is present, which is usually the case in lumber passing through industrial processes. For veneers or thin plywood, however, the surface contacts are more satisfactory.

A study of moisture distribution in drying boards and planks has shown that, after the entire piece has a moisture content below 25 to 30 percent, the moisture content in a plane about one-fifth of the thickness of the material from its surface is usually close to the average moisture content of the piece. When using a needle-point type of electrode in wood containing a typical drying distribution of moisture, the moisture meter indicates the moisture content at or near the points of the needles. Because of this fact, it is possible to determine the average moisture content by driving the needles to a depth of about one-fifth the thickness of the piece. In the case of heavy members, finishing nails may be used instead of the needles and may be driven to any desired depth.

Factors that influence the accuracy of resistance-type electric moisture meters are:

a. *Surface moisture.*—This type of meter will not give satisfactory readings on lumber moistened by rain or fog, since only the surface moisture content will be shown. When used in wet weather, the instrument itself may become damp, thereby preventing readings at low moisture content values.

b. *Temperature.*—Temperature affects the accuracy of resistance-type moisture meters. The measured resistance of the wood increases with a falling temperature and decreases as the temperature rises. Measurements above 100° F. or below 30° F. are not recommended because of lack of satisfactory temperature correction data. Corrections for temperatures between 30° and 100° F. are easily made, and man-

ufacturers usually supply the necessary correction factors.

c. *Species variations.*—Variations between species must be taken into account. Fortunately, reasonably accurate corrections for species variations can be made, and makers usually furnish correction data for their instruments.

3.613. Capacity or Radio-frequency Power-loss Moisture Meters.—When the electrodes of a capacity, or radio-frequency power-loss, meter are brought into contact with wood, the flow of electric current in one branch of the oscillator circuit is affected by the moisture content of the wood adjacent to the electrodes and the moisture content can thus be evaluated. Meters of this type are generally supplied with an arbitrary scale and a table giving the corresponding moisture content readings for a number of species of wood commonly used. In some cases a calibration for Douglas-fir or another species is used. The capacity or radio-frequency power-loss methods are, in principle, excellent means of evaluating the quantity of water, by weight, in wood. To convert the evaluation of the weight of water to a percentage moisture content it is necessary to know the weight or specific gravity of the wood. This property cannot be determined quickly enough by any method now available; therefore it is present practice to assume that the specific gravity of the individual piece when dry is the same as the average for the species. On this basis, the meters are calibrated, usually for a range of 0 to 25 percent moisture content. Capacity and radio-frequency power-loss moisture meters make contact with the wood with metal plates on the same side of the board under test.

Factors that may affect the accuracy of the moisture content determinations include:

a. *Variation in specific gravity.*—Since an assumed specific gravity has to be used for calibrating capacity-type moisture meters, each reading on such a meter carries an error proportional to the actual error in the assumed specific gravity of the piece.

b. *Moisture distribution.*—Moisture distribution may affect the readings of meters using condenser plates on one side only of the piece under test.

c. *Rough surfaces.*—Extremely rough surfaces that do not permit full contact of the condenser plates may affect the accuracy of readings .

3.614. Limitations of Moisture Meters.—Improper use of either resistance, capacity, or radio-frequency power-loss electric moisture meters will cause erroneous readings. In most cases they are designed for certain thicknesses of wood and, if used indiscriminately, incorrect observations are probable. Surfaces that have been treated with paint, varnish, lacquer, dope, and other finish materials do not as a rule affect the accuracy of electric moisture meters. In testing veneer and thin lumber with certain types of meters, care should be exercised to make certain that the readings are not influenced by the character of the material upon which the veneer or lumber is placed during the test. Veneers are easily split by needles, in which case contact is poor and incorrect readings are possible. Where needles penetrate glue lines there is some danger that the glue lines may contain electrolytes whose conductivity will obscure the actual moisture content of the wood.

3.7. SHRINKAGE AND SWELLING.

3.70. Wood.—Theoretically, shrinkage of wood below the fiber-saturation point is directly proportional to the amount of moisture lost. A curve showing the relationship of shrinkage to average moisture content, however, is rarely a straight line because of the presence of a moisture gradient in the wood (fig. 3–5). Shrinkage values for numerous woods used in housing are given in table 3–2.

When wood reaches approximate equilibrium with the temperature and relative humidity of the surrounding atmosphere it may swell or shrink as atmospheric conditions change. This does not mean, however, that the daily temperature and relative humidity changes that occur have any pronounced effect on wood. The rate of exchange of moisture between wood and atmosphere is comparatively slow, and the equilibrium moisture content of the wood is based on the average humidity prevailing over an extended period rather than on changes during very short periods, even though fluctuations may then be through a wide range. Thickness of the wood is also a factor, the moisture content of thin material reacting to atmospheric changes more rapidly than that of thick material.

Table 3-2.—*Shrinkage values for housing woods*

Species	Shrinkage (percent of dimension when green) from green to—								
	Air dried to 12 to 15 percent moisture [1] (estimated values)			Kiln dried to 6 to 7 percent moisture [2] (estimated values)			Oven dried to 0 percent moisture (test values)		
	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric	Radial	Tangential	Volumetric
HARDWOODS	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ash, black	2.5	3.9	7.6	3.8	5.8	11.4	5.0	7.8	15.2
Ash, commercial white [3]	2.3	3.8	6.4	3.4	5.6	9.6	4.6	7.5	12.8
Basswood, American	3.3	4.6	7.9	5.0	7.0	11.8	6.6	9.3	15.8
Beech, American	2.6	5.5	8.2	3.8	8.2	12.2	5.1	11.0	16.3
Birch	3.4	4.4	8.2	5.2	6.7	12.2	6.9	8.9	16.3
Chestnut, American	1.7	3.4	5.8	2.6	5.0	8.7	3.4	6.7	11.6
Cottonwood, eastern	2.0	4.6	7.0	2.9	6.9	10.6	3.9	9.2	14.1
Elm, American	2.1	4.8	7.3	3.2	7.1	11.0	4.2	9.5	14.6
Elm, rock	2.4	4.0	7.0	3.6	6.1	10.6	4.8	8.1	14.1
Hackberry	2.4	4.4	6.9	3.6	6.7	10.4	4.8	8.9	13.8
Magnolia, southern	2.7	3.3	6.2	4.0	5.0	9.2	5.4	6.6	12.3
Maple, red	2.0	4.1	6.6	3.0	6.2	9.8	4.0	8.2	13.1
Maple, silver	1.5	3.6	6.0	2.2	5.4	9.0	3.0	7.2	12.0
Maple, sugar	2.4	4.8	7.4	3.7	7.1	11.2	4.9	9.5	14.9
Oak, commercial red [4]	2.2	4.5	7.4	3.2	6.8	11.1	4.3	9.0	14.8
Oak, commercial white [5]	2.7	4.6	8.0	4.0	7.0	12.0	5.4	9.3	16.0
Sweetgum	2.6	5.0	7.5	3.9	7.4	11.2	5.2	9.9	15.0
Sycamore, American	2.6	3.8	7.1	3.8	5.7	10.6	5.1	7.6	14.2
Tupelo, black	2.2	3.8	7.0	3.3	5.8	10.4	4.4	7.7	13.9
Tupelo, water	2.1	3.8	6.2	3.2	5.7	9.4	4.2	7.6	12.5
Walnut, black	2.9	4.4	6.3	4.3	6.6	9.5	5.8	8.8	13.0
Yellow-poplar	2.0	3.6	6.2	3.0	5.3	9.2	4.0	7.1	12.3
SOFTWOODS									
Baldcypress	1.9	3.1	5.2	2.8	4.6	7.9	3.8	6.2	10.5
Douglas-fir	2.5	3.9	5.9	3.8	5.8	8.8	5.0	7.8	11.8
Fir, noble	2.2	4.1	6.2	3.4	6.2	9.4	4.5	8.3	12.5
Fir, white	1.6	3.5	4.7	2.4	5.2	7.0	3.2	7.0	9.4
Hemlock, western	2.2	4.0	6.0	3.2	5.9	8.9	4.3	7.9	11.9
Larch, western	2.1	4.0	6.6	3.2	6.1	9.9	4.2	8.1	13.2
Pine, eastern white	1.2	3.0	4.1	1.7	4.5	6.2	2.3	6.0	8.2
Pine, loblolly	2.4	3.7	6.2	3.6	5.6	9.2	4.8	7.4	12.3
Pine, longleaf	2.6	3.8	6.1	3.8	5.6	9.2	5.1	7.5	12.2
Pine, ponderosa	2.0	3.2	4.8	2.9	4.7	7.2	3.9	6.3	9.6
Pine, red	2.3	3.6	5.8	3.4	5.4	8.6	4.6	7.2	11.5
Pine, shortleaf	2.2	3.8	6.2	3.3	5.8	9.2	4.4	7.7	12.3
Pine, sugar	1.4	2.8	4.0	2.2	4.2	5.9	2.9	5.6	7.9
Pine, western white	2.0	3.7	5.9	3.1	5.6	8.8	4.1	7.4	11.8
Redcedar, western	1.2	2.5	3.8	1.8	3.8	5.8	2.4	5.0	7.7
Redwood	1.3	2.2	3.4	2.0	3.3	5.1	2.6	4.4	6.8
Spruce [6]	2.2	3.9	6.2	3.2	5.8	9.2	4.3	7.8	12.3
White-cedar, northern	1.0	2.4	3.5	1.6	3.5	5.2	2.1	4.7	7.0
White-cedar, Port Orford	2.3	3.4	5.0	3.4	5.2	7.6	4.6	6.9	10.1
Yellow-cedar, Alaska	1.4	3.0	4.6	2.1	4.5	6.9	2.8	6.0	9.2

[1] These shrinkage values have been taken as one-half the shrinkage to the oven-dry condition as given in the last three columns of this table.
[2] These shrinkage values have been taken as three-fourths the shrinkage to the oven-dry condition as given in the last three columns of this table.
[3] Average of Biltmore white ash, blue ash, green ash, and white ash.
[4] Average of black oak, eastern red oak, laurel oak, northern red oak, pin oak, scarlet oak, southern red oak, swamp red oak, water oak, and willow oak.
[5] Average of bur oak, chestnut oak, post oak, swamp chestnut oak, swamp white oak, and white oak.
[6] Average of red spruce, Sitka spruce, and white spruce.

Since, in seasoning green wood, the surface dries more rapidly than the interior and reaches the fiber-saturation point first, shrinkage may start near the surface of a piece while the average moisture content of the board or timber is still considerably above the fiber-saturation point. Wood shrinks most in the direction of the annual growth rings (tangentially), about one-half to two-thirds as much across these rings (radially), and very little, as a rule, along the grain (longitudinally). The combined effects of radial and tangential shrinkage on the shape of various sections in drying from the green condition are illustrated in figure 3–6.

In general, the heavier species of wood shrink more across the grain than the lighter ones. Heavier wood of the same species also shrinks more in this direction than lighter wood.

3.71. Plywood.—Although plywood made of hot-setting synthetic-resin glues is highly water-resistant, the fact that these glues prevent

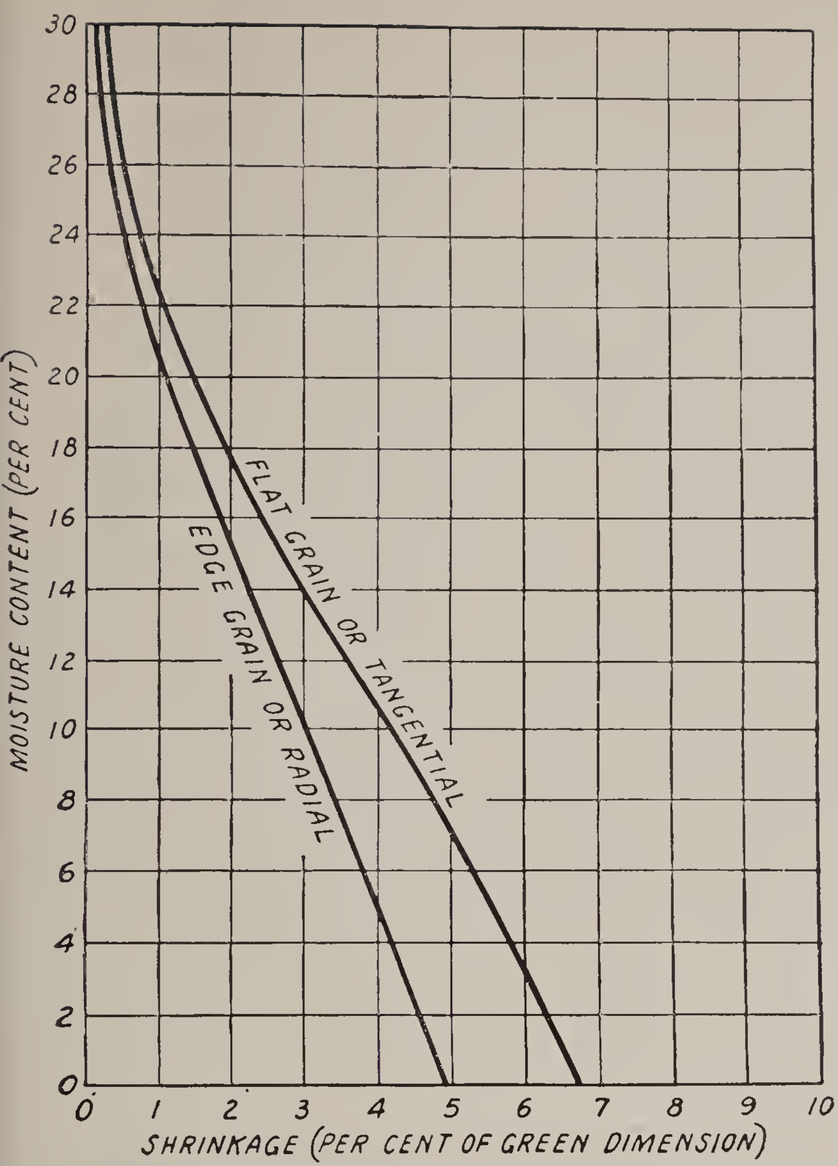


FIGURE 3–5.—Typical moisture content-shrinkage curves for Douglas-fir and southern yellow pine. Although the curves are not straight lines, for practical shrinkage calculations they may be considered as such.

the delamination of plywood even when exposed to prolonged periods of soaking or exposure to high humidity does not mean that they make the plywood impervious to penetration by moisture. Such plywood will absorb moisture throughout its structure in much the same manner as does solid wood.

Since the longitudinal shrinkage of wood is negligible, the lateral shrinkage of adjacent plies whose grain is at right angles will be restrained. The shrinkage of a plywood panel in the two lateral directions is therefore restrained. This shrinkage varies with the species of wood used, the ratio of ply thicknesses, the number of plies, the character of the grain, and the combination of species. Because its shrinkage in the thickness direction is unopposed, plywood will shrink as much as normal wood in thickness; in fact, since shrinkage of the wood is curbed in the lateral directions, this shrinkage is compensated for either internally or by a slightly increased shrinkage in the thickness direction.

The average shrinkage obtained from several hundred tests on a variety of combinations of species and thicknesses in bringing three-ply plywood from the soaked to the oven-dry condition was about 0.45 percent parallel to the face grain and 0.67 percent perpendicular to the face grain. The tests showed that the lateral shrinkage of plywood is only about one-tenth that of solid wood across the grain.

3.8. RESISTANCE OF WOOD TO DECAY, INSECTS, WEATHERING, FIRE.

3.80. General.—Aside from strength (ch. 5), wood has certain properties in varying degree that greatly influence its suitability for use in housing. Among these are its resistance to decay, insects, weathering, and fire.

3.81. Decay.—The fungi that cause decay (sec. 2.39) should not be confused with the animal forms, such as termites, which can cause as much damage to wood as decay fungi. The fungi causing decay in buildings are different species than those occurring in trees. Where wood is used in houses under adverse conditions it may rot for one of four reasons:

(1) The decay fungus becomes established in the wood either in the lumber yard or on the building site, generally because of improper handling.

(2) The wood is used in contact with moist soil.

(3) Water-conducting fungi draw moisture from the soil up to the wood. Such fungi have been known to cause very extensive damage, particularly in the South.

(4) Inadequate ventilation and poor construction produce localized moisture conditions favorable for decay fungi.

There is also chance for confusion of decay with discoloration, weathering, or disintegration due to other causes. Among these are the chemical blackening (due to the reaction of iron to tannic acid) that usually takes place next to iron fastenings and the disintegration due to chemical or physical causes that sometimes occurs in special situations. Wood long acted upon by battery liquids or fumes, some softwoods subjected to alternate freezing and thawing while very wet, and timbers near boilers or other sources of very high tempera-

ture are examples of special cases of disintegration. These chemical or physical injuries may show as a softening resembling decay or as shredding and separation of fibers or annual rings that individually still remain fairly hard and are, therefore, quite different from wood that has been attacked by the decay fungi.

Much can be done to prevent decay by avoiding the moisture conditions that favor it.

Comparison of the relative decay resistance of different species must be estimates. They cannot be exact, and they may be extremely misleading if considered mathematically accurate and universally applicable. Such comparisons in years of service may be useful, however, if regarded as approximate averages only, from which individual pieces or lots of a given species may vary considerably, and if they are understood to apply only where the wood is subject to conditions that favor decay.

Unless treated with preservatives, the sapwood of substantially all species has low resistance to decay and usually has short life under conditions favoring decay fungi.

The relative decay resistance of the heartwood of the species commonly used is indicated in the following grouping of species. This grouping divides some of the more common native species into five classes listed in accordance with the resistance of heartwood to decay; every grouping of this nature is subject to the preceding limitations. The classification is based on service records, where available, and on general experience.

Heartwood highly durable even when used under conditions that favor decay	Baldcypress Chestnut, American Redcedar, Eastern Redcedar, Western Redwood Walnut, black White-cedar, Atlantic White-cedar, Northern White-cedar, Port Orford Yellow-cedar, Alaska
Heartwood of intermediate durability but nearly as durable as some of the species named in the high-durability group	Douglas-fir (dense) Oak, white Pine, southern yellow (dense)
Heartwood of intermediate durability	Douglas-fir (unselected) Larch, Western Pine, southern yellow (unselected) Sweetgum
Heartwood between the intermediate and the nondurable group	Ash, commercial white Beech, American Birch, sweet Birch, yellow Elm, American Elm, rock Elm, slippery Hemlock, Eastern Hemlock, Western Maple, sugar Oak, red Pine, Eastern white[3] Pine, sugar[3] Pine, Western white[3] Spruce, black Spruce, Engelmann Spruce, red Spruce, Sitka Spruce, white Tupelo, black Tupelo, water
Heartwood low in durability when used under conditions that favor decay	Basswod, American Cottonwood Fir, commercial white Pine, ponderosa[3] Pine, red[3]

[3] Conflicting opinion and absence of adequate test data preclude a definite rating; reliance on high decay resistance is not recommended when this species is used untreated.

Decay-susceptible woods should be used only where they are not in contact with soil or water or where it is practicable to give them thorough treatment with good preservatives, as described in chapter 6.

3.82. Insects.—Of the various insects that attack wood, two kinds are chiefly responsible for the damage that occurs in dry lumber installed in houses, according to the Division of Forest Insect Investigations, Bureau of Entomology and Plant Quarantine. These are powderpost beetles and termites.

Powderpost beetles attack both freshly cut and seasoned hardwood lumber. The species of beetle that does most damage is the *Lyctus*, which attacks only the seasoned sapwood of hardwoods. Ash, hickory, and oak are principally affected, but walnut, maple, elm, yellow-poplar, sycamore, persimmon, and cherry are sometimes attacked. These beetles are especially likely to damage hardwood lumber and millwork that are left undisturbed in storage for long periods. Eggs are laid in the pores of the wood, and the larvæ burrow through the wood, making holes about one-sixteenth to one-twelfth inch in diameter. As the larvæ become winged

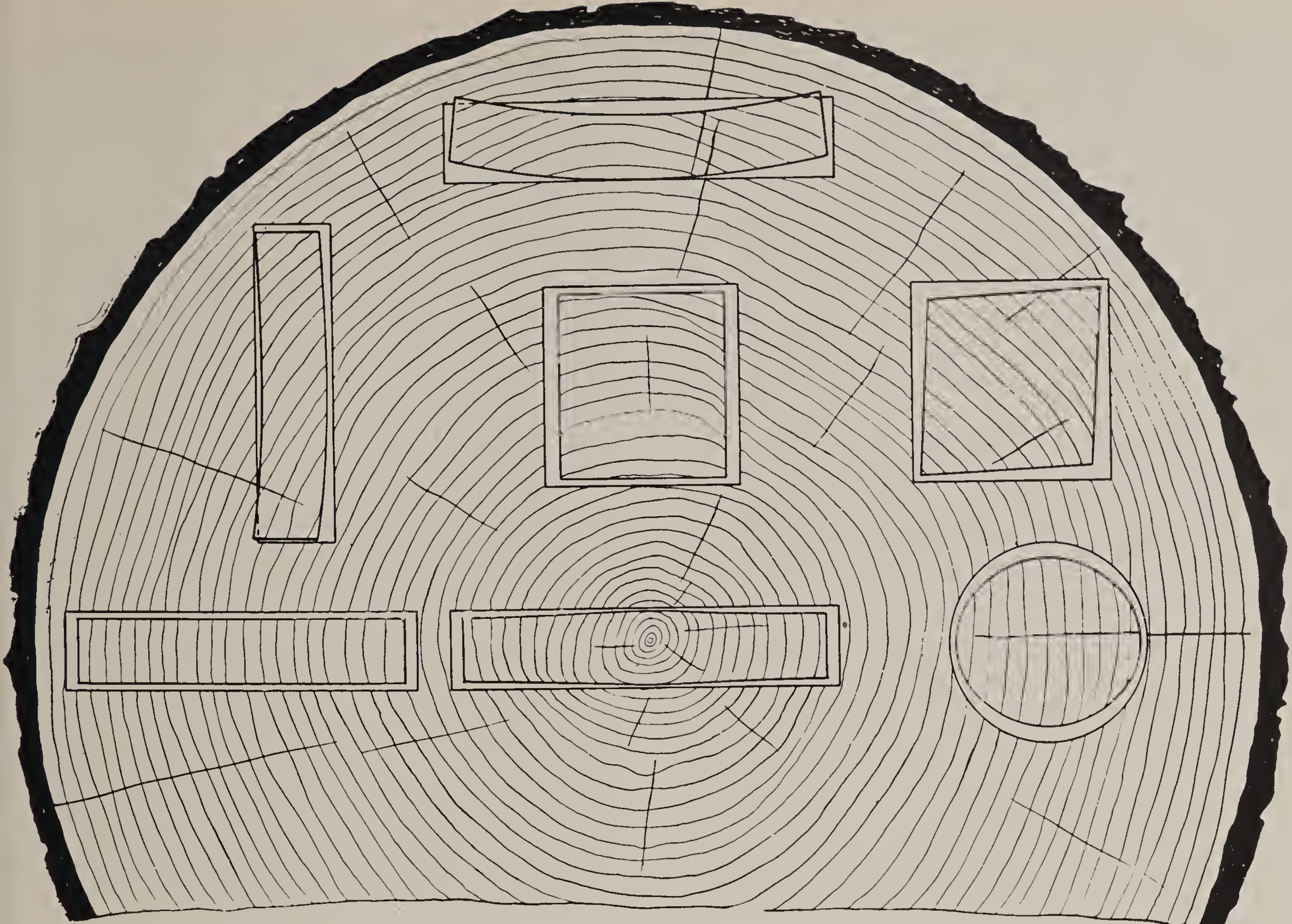


FIGURE 3-6.—Characteristic shrinkage and distortion of flats, squares, and rounds as affected by the direction of the annual rings. Tangential shrinkage is about twice as great as radial. The dimensional changes shown are somewhat exaggerated.

adult beetles and emerge from the trim, flooring, and other woodwork, they leave tell-tale holes in the wood and fine powder about the holes (fig. 3-7). Methods of controlling these insects are given in chapter 6.

Other powderpost beetles attack seasoned softwood and differ from the above in that they infest both sapwood and heartwood. They attack sills, joists, subflooring, and rafters.

Termites superficially resemble ants in size, general appearance and their habit of living in colonies. They are frequently called "white ants." About 56 species of termites are known in the United States, and hundreds more in other countries. From the standpoint of their methods of attack on wood, the termites of the United States can be grouped into two main classes: (1) ground-inhabiting or subterranean termites and (2) dry-wood termites. Subterranean termites are found in nearly every State and are responsible for most of the termite damage to wood structures. Dry-wood termites are found only in a narrow strip of territory extending from central California, just north of San Francisco, south and east along the southern border of the country and as far north along the Atlantic Coast as Virginia.

The subterranean termites develop their colonies in the ground, from which they build tunnels (fig. 3-8) through earth and around obstructions to get at the wood they need for food. These termites must have a constant source from which to obtain moisture or they will die. The worker members of the colony cause the destruction of wood (fig. 3-9, *B*). At certain seasons of the year, male and female winged forms (fig. 3-9, *A*) swarm from the colony, fly a short time, lose their wings, mate, and if successful in locating a suitable place they start new colonies. Soldier termites (fig.

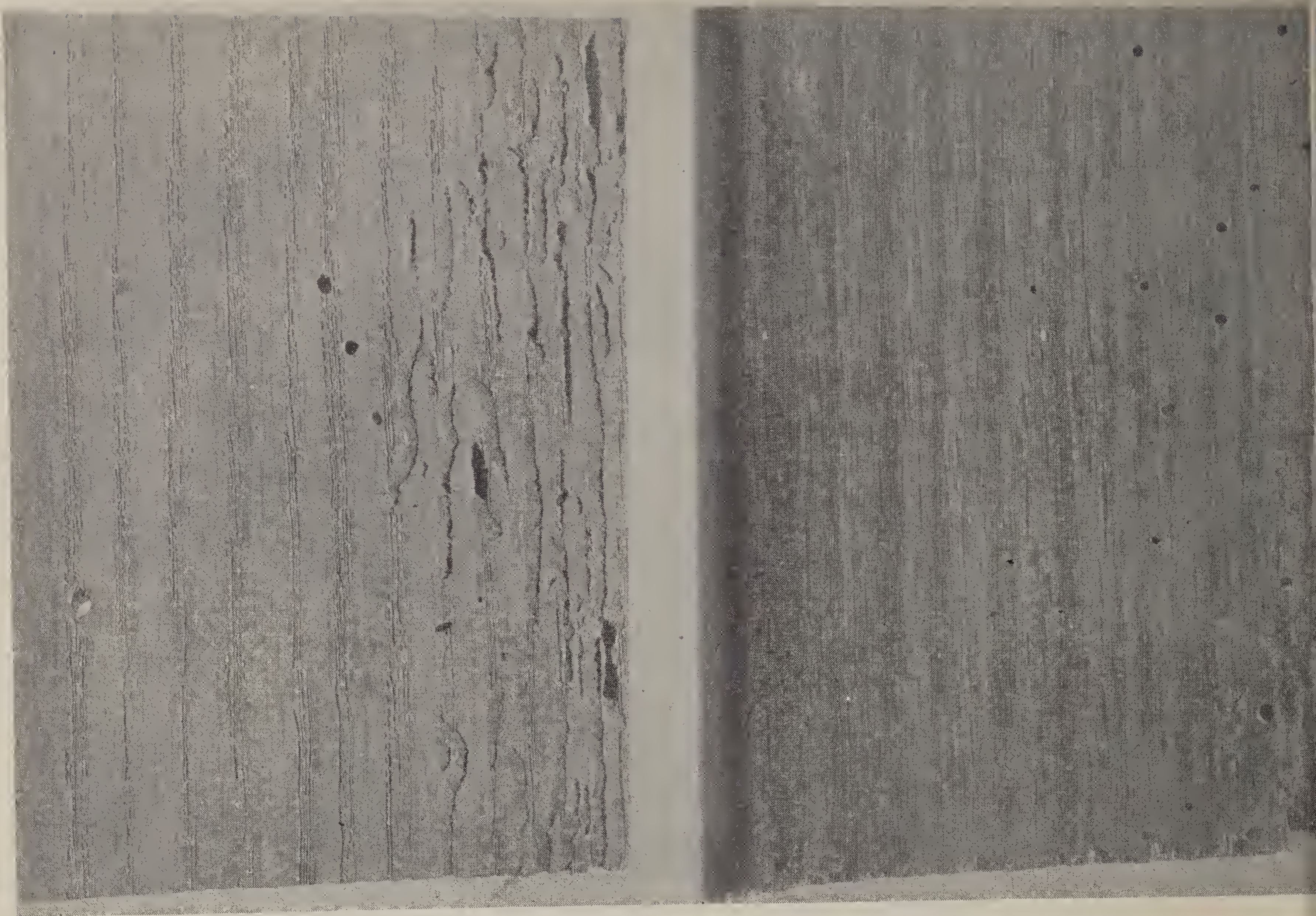


FIGURE 3–7.—Typical damage caused by powderpost beetles.

3–9, *C*) are the protectors of the colony from natural enemies. The appearance of "flying ants" is an indication that a termite colony is near and perhaps causing serious damage unnoticed.

Subterranean termites do not establish themselves in buildings by being carried in in lumber but by entering from ground nests after the building has been constructed. If unmolested, they eat out the woodwork, leaving a shell of sound wood to conceal their activities. The damage may proceed so far as to cause collapse of portions of the structure before discovery (fig. 3–10).

Dry-wood termites are fewer in numbers, do not multiply so rapidly, and have colony life and habits somewhat different from those of the subterranean termites. They cause much less damage than the subterranean class. Because they can live in dry wood without outside moisture or contact with the ground, however, they are a definite menace in the regions where they occur. While their depredations are slow, they can riddle timbers with their tunnellings if allowed to work unmolested for a few years.

Only a limited number of woods grown in the United States offer any marked degree of resistance to termite attack. Redwood and baldcypress have some resistance, especially where used above ground, but termites are known to attack them at times. Very resinous heartwood of southern yellow pine is practically immune, but is not available in large quantities, nor is it suitable for many uses.

3.83. Fire.—In the use of wood, or any other combustible material, for house construction, fire hazards are rightly a matter of prime consideration to the builder. Adherence to certain principles of good design is fundamental in reducing these hazards to a minimum and building a safe structure. While fire hazards are not great in the average dwelling, the matter

FIGURE 3–8.—Termite shelter tubes on a concrete wall enclosing a crawl space. The runway tunnels connect sources of supplies essential to termite existence—food found in wood and moisture in the soil.

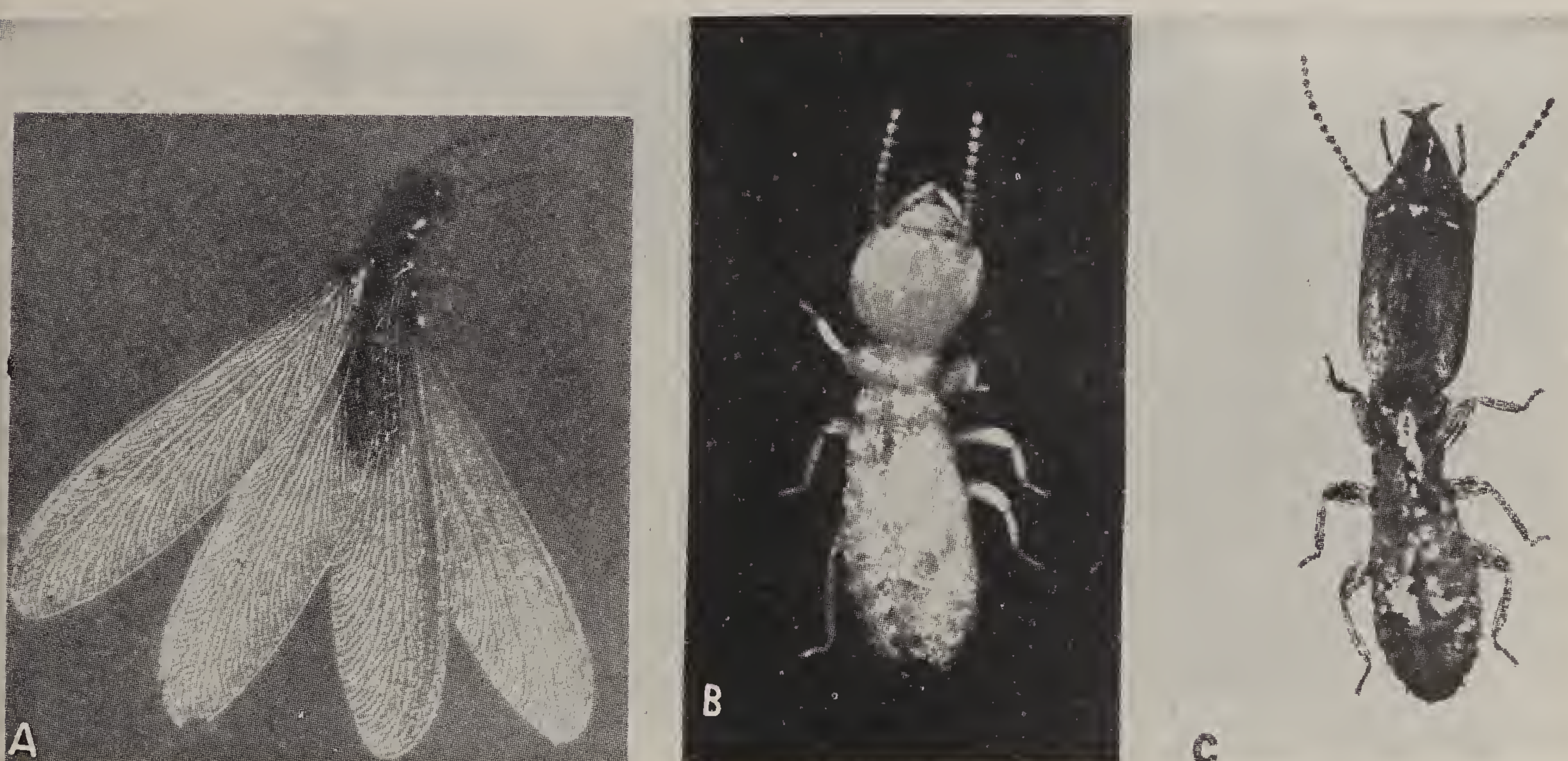


FIGURE 3–9.—Termites. *A*, winged reproductive; *B*, worker; *C*, soldier termite. (Greatly enlarged.)

FIGURE 3–10.—Termite-destroyed piece of wood

of minimizing such hazards warrants constant attention on the part of the designer and builder. Among design factors of prime importance are provision for adequate clearance between sources of heat, such as chimneys, fireplaces, and heating appliances, and combustible elements of the house; and the employment of methods for increasing the fire resistance of materials (sec. 6.3).

While various methods have been devised for assigning fire-resistive values to wood and other combustible materials used in housing, they do not furnish an entirely safe basis for design, since there is no certain means of forecasting with absolute assurance that temperatures higher than those anticipated will not occur at critical points in houses under certain conditions of use, maintenance, or carelessness of the occupants. Fire hazards, therefore, are not so much a matter of the ignition point of building materials as of proper design and good workmanship. With conventional building materials, hazards can be reduced to the point where, with reasonably good maintenance an care on the part of occupants, the probabilit of fire in any particular home is negligible.

3.84. Weathering.—Boards exposed to th weather without protective coating rapidly b come weathered. Weathering may involv change in color, roughening and checking o the surface, and, if one side of the board onl is fully exposed, cupping and tearing loos from fastenings, but it does not include deca With all species, quarter-sawed or edge-grai boards check less conspicuously and cup le than plain-sawed or flat-grain boards of th same species. Twisting, another although le common effect of weathering, is caused pr marily by uneven shrinkage resulting fro spiral and interlocked grain; it is more pr nounced in flat-grain and plain-sawed than i edge-grain and quarter-sawed boards. Weathe ing, as a rule, changes all woods to a gray colo darker in some than in others, and attracti when accompanied by a silvery sheen, as often is.

GRADING OF LUMBER AND PLYWOOD

4.0. GRADES AND SIZES OF LUMBER.

4.00. General.—A large tree when sawed into lumber yields boards of widely varying quality. Lumber grades divide the product of the tree into several segregations each having a relatively narrow range in quality which enables each user to buy the quality that best suits his use and purpose.

Except as noted later, the grade of a piece of lumber is based on the number, character, and location of such things as knots, pitch pockets, and the like, which are commonly referred to as defects and are defined as "any irregularity occurring in or on wood that may lower some of its strength, durability, or utility values." Among the more common defects are knots, checks, pitch pockets, shake, and stain, some of which are a natural part of the tree. The best grades are free or practically free from these things, while the others, comprising the great bulk of lumber, contain fairly numerous knots and other defects. These defects, however, do not prevent such lumber from giving satisfaction for many wide-spread uses.

Following is a list of the principal lumber and plywood manufacturers' associations and the woods graded under the rules of each association:

LUMBER MANUFACTURERS' ASSOCIATIONS

Name and address	*Woods covered*	*Grading rules used*
American Walnut Manufacturers' Association, 616 South Michigan Avenue, Chicago, Ill.	Black Walnut	Covered by rules of National Hardwood Lumber Association.
Appalachian Hardwood Manufacturers, Inc., 414 Walnut Street, Cincinnati, Ohio.	Appalachian oak and yellow-poplar.	Covered by rules of National Hardwood Lumber Association.
California Redwood Association, 405 Montgomery Street, San Francisco 4, Calif.	Redwood	Formulate and administer their own rules.
Hardwood Dimension Manufacturers' Association, 230 Heyburn Building, Louisville 2, Ky.	Various hardwoods	Commercial Standards CS 89–40, CS 76–39, CS 60–36, and CS 74–39.
Mahogany Association, Incorporated, 75 East Wacker Drive, Chicago, Ill.	Mahogany	Covered by rules of National Hardwood Lumber Association.
Maple Flooring Manufacturers' Association, 332 South Michigan Avenue, Chicago 4, Ill.	Maple (northern hard), beech, birch.	Formulate and administer their own rules.
National Hardwood Lumber Association, 59 East Van Buren Street, Chicago, Ill.	Various hardwoods, cypress, aromatic redcedar.	Formulate and administer their own rules.
National Lumber Manufacturers' Association, 1319 Eighteenth Street NW., Washington, D. C.	Various hardwoods and softwoods.	Follow rules of member associations.
National Oak Flooring Manufacturers' Association, 830 Dermon Building, Memphis 3, Tenn.	Oak, pecan, beech, birch, and hard maple.	Formulate and administer their own rules.
Northeastern Lumber Manufacturers' Association, Inc., 271 Madison Avenue, New York 16, N. Y.	White pine, Norway pine, spruce, and balsam fir.	Formulate and administer their own rules. Also use rules of National Hardwood Lumber Association for hardwoods and Northern hemlock, and Hardwood Manufacturers' Association rules for hemlock.

Name and address	Woods covered	Grading rules used
Northern Hemlock and Hardwood Manufacturers' Association, Oshkosh, Wis.	Hemlock, tamarack, Northern white pine, and Northern white-cedar.	Formulate and administer own rules. Also use rules of National Hardwood Lumber Association and Northern Pine Association.
Northern Pine Manufacturers' Association, 4438 Wentworth Avenue, Minneapolis 9, Minn.	Northern white pine, Norway pine, Eastern spruce, and jack pine.	Formulate and administer their own rules.
Southern Cypress Manufacturers' Association, 722 Barnett Bank Building, Jacksonville, Fla.	Southern cypress (upland and tidewater types).	Formulate and administer their own rules.
Southern Hardwood Producers, Inc., 805 Sterrick Building, Memphis, Tenn.	Southern hardwoods	Use rules of National Hardwood Lumber Association.
Southern Pine Association, 520 Canal Building, New Orleans 4, La.	Southern yellow pine	Use rules of Southern Pine Inspection Bureau.
Southern Pine Inspection Bureau, New Orleans, La.	Southern yellow pine	Formulate and administer their own rules.
West Coast Bureau of Lumber Grades and Inspection, 804 Yeon Building, Portland 4, Oreg.	Douglas-fir, Sitka spruce, Western hemlock, and Western redcedar.	Formulate and administer their own rules.
West Coast Lumbermen's Association, 364 Stuart Building, Seattle, Wash.	Douglas-fir, Sitka spruce, Western hemlock, and Western redcedar.	Use rules of West Coast Bureau of Lumber Grades and Inspection.
Western Pine Association, 510 Yeon Building, Portland 4, Oreg.	Ponderosa pine, Idaho white pine, sugar pine, Western larch, Douglas-fir ("Inland Empire" and California), white fir, Engelmann spruce, incense cedar, and Western redcedar.	Formulate and administer their own rules.

SHINGLE MANUFACTURERS' ASSOCIATIONS

Red Cedar Shingle Bureau, 5508 White Building, Seattle 1, Wash.	Western redcedar (shingles).	Formulate and administer their own rules.

PLYWOOD MANUFACTURERS' ASSOCIATIONS

Douglas Fir Plywood Association, 301 Tacoma Building, Tacoma, Wash.	Douglas-fir plywood and Western hemlock plywood.	U. S. Commercial Standards CS 45–45 and CS 122–45.
Hardwood Plywood Institute 616 South Michigan Avenue, Chicago 5, Ill.	Various hardwoods	Use rules of National Hardwood Lumber Association and Commercial Standard CS 35–42.
The Veneer Association, 1455 Clavey Court, Highland Park, Ill.	Hardwood veneers	Use rules of National Hardwood Lumber Association.

Lumber is graded according to three systems or use-classifications: (1) yard, (2) factory and shop, and (3) structural. Yard lumber is that commonly carried in retail yards for use in general building construction. Factory and shop lumber is that intended for cutting-up purposes in the manufacture of fabricated and factory products. Structural material includes timber and heavy dimension for structural purposes where working stresses are required and defects are limited according to their effect on the strength of the piece as a whole.

Both softwoods and hardwoods are graded according to each of the three above classifications. Hardwoods, however, are graded mainly according to the factory classification. In the case of softwoods, all three classifications are used in substantial degree.

4.01. Hardwood Lumber Grading.

4.010. Hardwood Factory Lumber (All Species).—The rules which are considered standard in grading hardwood lumber in the United States are those adopted by the National Hardwood

Lumber Association.[1] [2] In these rules the grade of a piece of hardwood lumber is determined by the proportion of the piece that can be cut into a certain number of smaller pieces of material clear on one side and not less than a certain size. In other words, the grade classification is based upon the amount of usable lumber in the piece rather than upon the number or size of the defects. This material, commonly termed "cuttings," must have one face clear and the reverse face sound, which means free from rot, heart center, shake, and other defects that materially impair the strength of the cutting. Some grades require only that cuttings be sound.

The highest grade of hardwood lumber is termed "Firsts" and the next grade "Seconds." Firsts and Seconds, or as they are generally written, "FAS," practically always are combined in one grade. The third grade is termed "Selects," followed by No. 1 Common, No. 2 Common, Sound Wormy, No. 3A Common, and No. 3B Common.

The hardwood grading provisions described herein, although not incorporated in American lumber standards, have been accepted by the central committee on lumber standards as being in accord with its published recommendations for both basic grades and species nomenclature.

A brief summary of the hardwood grades is given below. This summary should not be regarded as a complete set of grading rules, as there are numerous details, exceptions, and special rules for certain species that are not included. The complete official rules of the association should be followed as the only full description of existing grades (Hardwood Interior Trim Manufacturers' Association, Maple Flooring Manufacturers' Association, National Hardwood Lumber Association, and National Oak Flooring Manufacturers' Association). The summary is intended only as a preliminary guide in distinguishing between the general qualities to be expected under the various grades.

[1] This association publishes a booklet which contains detailed grading rules for various hardwood products, such as lumber, flooring, and vehicle stock. The association maintains bonded lumber inspectors in various hardwood producing and consuming centers who issue, under special arrangement, inspection certificates on shipments. The correctness of the grades as shown on these certificates is guaranteed by the association.

[2] For further information, the references at the end of this section should be consulted.

4.0100. Summary of Standard Grades of the National Hardwood Lumber Association.—The commercial woods used most by prefabricators, for which grading rules have been set up by the National Hardwood Lumber Association, are:[3]

Ash
Basswood
Beech
Birch
Butternut
Cedar, red
Chestnut
Cottonwood
Cypress
Elm:
  Rock (or cork)
  Soft
Gum:
  Black
  Red and sap
  Tupelo
Hickory
Magnolia
Mahogany:
  African
  Cuban and San Dominican
  Tropical American
  Philippine
Maple:
  Hard (or sugar)
  Soft
Oak:
  Red and White
Poplar
Sycamore
Walnut
Willow

Standard lengths are 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16 feet, but not over 50 percent of odd lengths will be admitted.

Standard thicknesses for hardwood lumber are given in table 4–1.

TABLE 4–1.—*Standard thicknesses for hardwood lumber*

Rough	Surfaced 1 side (S1S)	Surfaced 2 sides (S2S)	Rough	Surfaced 1 side (S1S)	Surfaced 2 sides (S2S)
Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
3/8	1/4	3/16	2 1/2	2 5/16	2 1/4
1/2	3/8	5/16	3	2 13/16	2 3/4
5/8	1/2	7/16	3 1/2	3 5/16	3 1/4
3/4	5/8	9/16	4	3 13/16	3 3/4
1	7/8	13/16	4 1/2	([1])	([1])
1 1/4	1 1/8	1 1/16	5	([1])	([1])
1 1/2	1 3/8	1 5/16	5 1/2	([1])	([1])
2	1 13/16	1 3/4	6	([1])	([1])

[1] Finished size not specified in rules. Stock usually made in small quantities or on special order.

A description of the standard hardwood grades is given in table 4–2.

The highest grade, Firsts, calls for pieces which will allow 91⅔ percent of their surface measure to be cut into clear-face material; that

[3] Two of the woods included, namely cedar (Eastern redcedar) and cypress (baldcypress), are not hardwoods. Cypress lumber has a different set of grading rules from those used for the hardwoods. All cypress rules are originated by the Southern Cypress Manufacturers' Association and are either used verbatim or with minor changes by the National Hardwood Lumber Association.

TABLE 4–2.—*Standard hardwood grades* [1]

Grade, and lengths allowed (feet)	Widths allowed	Surface measure of pieces	Percentage of each piece that must work into clear-face cuttings	Maximum cuttings allowed	Minimum size of cuttings required
	Inches	*Square feet*	*Percent*	*Number*	
Firsts: [2] 8 to 16 (will admit 25 percent of 8- to 11-foot, half of which may be 8- and 9-foot).	6+	4 to 9	$91\frac{2}{3}$	1	4 inches by 5 feet, or 3 inches by 7 feet.
		10 to 14	$91\frac{2}{3}$	2	
		15+	$91\frac{2}{3}$	3	
Seconds: [2] 8 to 16 (will admit 25 percent of 8- to 11-foot, half of which may be 8- and 9-foot).	6+	4 and 5	$83\frac{1}{3}$	1	Do.
		6 and 7	$83\frac{1}{3}$	1	
		6 and 7	$91\frac{2}{3}$	2	
		8 to 11	$83\frac{1}{3}$	2	
		8 to 11	$91\frac{2}{3}$	3	
		12 to 15	$83\frac{1}{3}$	3	
		12 to 15	$91\frac{2}{3}$	4	
		16+	$83\frac{1}{3}$	4	
Selects: 6 to 16 (will admit 30 percent of 6- to 11-foot, one-sixth of which may be 6- and 7-foot).	4+	2 and 3	$91\frac{2}{3}$	1	Do.
		4+	(3)		
No. 1 Common: 4 to 16 (will admit 10 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	1	100	0	4 inches by 2 feet, or 3 inches by 3 feet.
		2	75	1	
		3 and 4	$66\frac{2}{3}$	1	
		3 and 4	75	2	
		5 to 7	$66\frac{2}{3}$	2	
		5 to 7	75	3	
		8 to 10	$66\frac{2}{3}$	3	
		11 to 13	$66\frac{2}{3}$	4	
		14+	$66\frac{2}{3}$	5	
No. 2 Common: 4 to 16 (will admit 30 percent of 4- to 7-foot, one-third of which may be 4- and 5-foot).	3+	1	$66\frac{2}{3}$	1	3 inches by 2 feet.
		2 and 3	50	1	
		2 and 3	$66\frac{2}{3}$	2	
		4 and 5	50	2	
		4 and 5	$66\frac{2}{3}$	3	
		6 and 7	50	3	
		6 and 7	$66\frac{2}{3}$	4	
		8 and 9	50	4	
		10 and 11	50	5	
		12 and 13	50	6	
		14+	50	7	
Sound Wormy: 4 to 16 (will admit 10 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	----------	(4)	---------	
No. 3A Common: 4 to 16 (will admit 50 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	1+	[5] $33\frac{1}{3}$	(6)	3 inches by 2 feet.
No. 3B Common: 4 to 16 (will admit 50 percent of 4- to 7-foot, half of which may be 4- and 5-foot).	3+	1+	25	(6)	$1\frac{1}{2}$ inches wide and containing at least 36 square inches.

[1] Inspection to be made on the poorer side of the piece, except in selects.
[2] Firsts and Seconds are combined as 1 grade (FAS). The percentage of Firsts required in the combined grade varies from 20 to 40 percent, depending on the species.
[3] Same as seconds.
[4] Cutting requirements same as in No. 1 Common, except that worm holes, bird pecks, sound stain, sound knots not over ¾ inch in diameter, and other similar sound defects will be admitted in the cuttings.
[5] This grade also admits pieces which grade not below No. 2 Common on the good face and have the reverse face sound.
[6] Not specified.
[7] The cuttings must be sound; clear face not required.

is, not more than $8\frac{1}{3}$ percent of each piece can be wasted in making the required cuttings. In the grade of Seconds, $83\frac{1}{3}$ percent of the surface measure of the pieces must yield clear-face cuttings.[4] Both Firsts and Seconds require pieces not less than 6 inches wide and 8 feet long. In the grade Selects the minimum width is 4 inches and the minimum length 6 feet. Both Firsts and Seconds and the face side of Selects must in addition to cutting requirements also meet specified requirements as to limitation of knots, holes, and the like. The cutting requirements of Selects are $91\frac{2}{3}$ percent clear face in pieces with 2 and 3 surface feet. In larger pieces the cutting requirements are the same as for Seconds on the face side. The reverse side of the cuttings in Selects must be sound or not below No. 1 Common. The next two

[4] Boards 6 to 15 feet surface measure will admit of one additional cutting to yield 91 2/3 percent clear face.

grades, No. 1 Common and No. 2 Common, call for material not less than 3 inches wide and 4 feet long and require[5] 66⅔ percent and 50 percent clear-face cuttings, respectively. The minimum size of cuttings in these two grades is reduced from 4 inches by 5 feet or 3 inches by 7 feet in Firsts, Seconds, and Selects to 4 inches by 2 feet or 3 inches by 3 feet.

In the grade of Sound Wormy the requirements are the same as in No. 1 Common except that worm holes and similar defects are allowed in the cuttings. The grade 3A Common admits pieces that will furnish 33⅓ percent clear face in cuttings not less than 3 inches wide and 2 feet long. This grade will also admit pieces that grade not below No. 2 Common on the good face and have the reverse face of the cutting sound. The lowest grade, No. 3B Common, allows pieces that will cut 25 percent in sound material not less than 1½ inches wide and having at least 36 square inches surface measure.

4.011. Hardwood Construction (Yard) Grades.—The rules of the National Hardwood Lumber Association recognize three classes of building lumber as distinct from the cutting grades. The building grades are graded much as in softwood construction lumber. These grades are "A" and "B" finish, No. 1, No. 2, and No. 3 construction boards, and No. 1 and No. 2 dimension. The nominal rough and dressed thicknesses are comparable to those of softwood construction lumber.

"A" finish is the highest grade, with one face practically clear of defects except for sound burls, slight discoloration, and small pin streaks.

"B" finish admits, in addition to those defects permissible in "A" finish, small surface checks and mineral streaks, mild stain that will not interfere with natural finish, and occasional sound knots not larger than three-fourths inch in diameter on the face side, as well as scattered pin worm holes, slight torn grain, and slight cup. The reverse side may contain a moderate amount of wane.

The No. 1 construction grade limits defects, including wane, to those that will not interfere with the use of the piece in its full size where it is to be painted. Lumber of this grade is not suitable for use with a natural finish. In the No. 2 construction grade, permissible defects are such as to limit its use to types of construction lumber such as wall and roof sheathing and sub-flooring. No. 3 construction lumber contains defects, without limit, of any character provided that the board as a whole is sufficiently sound to be used as low-grade sheathing or comparable parts.

Hardwood dimension lumber, in sizes suitable for studding, joists, and other structural members of houses, comes in two grades. No. 1 dimension is graded more strictly than No. 2 dimension lumber as to size and position of permissible defects, but both grades are intended for use without waste.

4.012. Hardwood Flooring.—Hardwood flooring is generally graded under the rules of the Maple Flooring Manufacturers' Association and the rules of the National Oak Flooring Manufacturers' Association. The National Hardwood Lumber Association has adopted the rules of the latter association. Tongue-and-groove and end-matched hardwood flooring is commonly furnished. Square-edge and square-end strip flooring is also available, as well as parquetry flooring suitable for laying on a mastic base or on an ordinary subfloor.

The Maple Flooring Manufacturers' Association grading rules cover flooring manufactured from sugar maple (hard maple),beech, and birch. Each species has the three grades designated as First grade, Second grade, and Third grade. There are also three special grades—White Clear Northern Hard Maple, Red Clear Northern Beech, and Red Clear Northern Birch, which are made up of special stock selected for uniformity of color. First grade flooring must have one face practically free from all defects. Variations in the natural color of the wood are allowed. Second grade flooring will admit tight, sound knots and slight imperfections but must lay without waste. Third grade flooring has no restrictions as to imperfections in the grain but must be of such a character that it can be properly laid and will give a good serviceable floor. The standard thickness of maple, beech, and birch flooring is twenty-five thirty-seconds inch. Faces or widths are 1½, 2, 2¼, and 3¼ inches. Standard lengths are from 2 to 16 feet

[5] Exceptions in No. 1 Common are pieces with 1 foot surface measure and 2 feet surface measure, which require 100 percent clear face and 75 percent clear face, respectively, and in No. 2 Common pieces with 1 foot surface measure, which require 66 percent clear face.

in First grade flooring and from 1 to 16 feet in Second grade and Third grade flooring.

The grading rules of the National Oak Flooring Manufacturers' Association cover quarter-sawed and plain-sawed oak flooring. Quarter-sawed flooring has three grades—Clear, Sap Clear, and Select. Plain-sawed flooring has four grades—Clear, Select, No. 1 Common, and No. 2 Common. The Clear grade in both plain- and quarter-sawed flooring must have one face practically free from surface imperfections except three-eighths inch of bright sap. Color is not considered in any grade. Sap Clear quarter-sawed flooring must have one face practically clear but will admit unlimited bright sap. Select flooring (plain- or quarter-sawed) may contain sap and will admit a few features such as pin worm holes and small tight knots. No. 1 Common plain-sawed flooring must contain material that will make a sound floor without cutting. No. 2 Common may contain grain and surface imperfections of all kinds but must be usable with some cutting in laying a serviceable floor. Standard thicknesses of oak flooring are 13/16, $\frac{1}{2}$, and $\frac{3}{8}$ inch. Standard widths are $1\frac{1}{2}$, 2, and $2\frac{1}{4}$ inches. Lengths in the upper grades are 2 feet and up, with a required average of 5 feet in a shipment. In the lower grades lengths are $1\frac{1}{4}$ feet and up, with a required average of $2\frac{1}{2}$ or 3 feet.

4.02. Softwood Lumber Grading.

4.020. General.—Softwood lumber, unlike hardwood lumber, is graded under a number of different association rules. Not only are the different kinds of softwoods graded under different rules, but the same softwoods in a number of cases are graded under different association rules.

In order to eliminate unnecessary differences in the grading rules of the various softwood lumber manufacturers' associations and to secure the improvement and simplification of these rules, American lumber standards were formulated. The standards themselves are issued in pamphlet form as simplified practice recommendations of the Bureau of Standards.

American lumber standards have been adopted in principle by the leading softwood lumber associations (California Redwood Association, Southern Cypress Manufacturers' Association, Southern Pine Association, West Coast Lumbermen's Association, Western Pine Association, and Northeastern Lumber Manufacturers' Association).

The names of lumber adopted by the trade as American lumber standards are not always identical with the names adopted as official by the Forest Service. Where the names are not identical some confusion may result. Table 4–3 has therefore been prepared to show the Amer-

TABLE 4–3.—*Nomenclature of commercial softwoods*

Official Forest Service name used in this manual	Name adopted as standard under American Lumber Standards	Other names sometimes used	Botanical name
		CEDARS AND JUNIPERS	
Alaska yellow-cedar	Alaska cedar	Yellow cedar, Sitka cypress, yellow cypress	*Chamaecyparis nootkatensis*
Northern white-cedar	Northern white cedar	Arborvitae, cedar, swamp cedar, white cedar	*Thuja occidentalis*
Atlantic white-cedar	Southern white cedar	White cedar, swamp cedar, juniper	*Chamaecyparis thyoides*
Western redcedar	Western red cedar	Red cedar, cedar, western cedar	*Thuja plicata*
		CYPRESS	
Baldcypress	Red cypress (coast type), yellow cypress (inland type), white cypress (inland type).	Cypress, tidewater red cypress, Gulf coast red cypress, Louisiana red cypress, southern cypress, red cypress, black cypress.	*Taxodium distichum*
		DOUGLAS-FIR	
Douglas-fir	Douglas fir (Coast region), Douglas fir (Inland empire and California), Douglas fir (Rocky Mountain region).	Red fir, Oregon fir, Douglas spruce, yellow fir, Puget Sound pine, Oregon pine.	*Pseudotsuga taxifolia*

Official Forest Service name used in this manual	Name adopted as standard under American Lumber Standards	Other names sometimes used	Botanical name
		THE TRUE FIRS	
California red fir	Golden fir	Red fir	*Abies magnifica*
Noble fir	Noble fir	do	*Abies procera*
Pacific silver fir	Silver fir	Red fir, white fir, silver fir	*Abies amabilis*
White fir	White fir	Colorado white fir	*Abies concolor*
Grand fir	do	Yellow fir	*Abies grandis*
		HEMLOCKS	
Eastern hemlock	Eastern hemlock	Hemlock, hemlock spruce, spruce pine	*Tsuga canadensis*
Western hemlock	West coast hemlock	Hemlock, hemlock spruce, Pacific hemlock, Alaska pine.	*Tsuga heterophylla*
		LARCH	
Western larch	Western larch	Tamarack, larch	*Larix occidentalis*
		PINES	
Western white pine	Idaho white pine	White pine, soft pine	*Pinus monticola*
Loblolly pine	Loblolly pine [1]	Old-field pine, slash pine, shortleaf pine, Virginia pine, sap pine, yellow pine, North Carolina pine.	*Pinus taeda*
Longleaf pine	Longleaf pine [1]	Southern pine, yellow pine, hard pine, Georgia pine, pitch pine, heart pine, fat pine, southern yellow pine.	*Pinus palustris*
Eastern white pine	Northern white pine	White pine, cork pine, soft pine, northern pine, pumpkin pine.	*Pinus strobus*
Red pine	Norway pine	Hard pine, northern pine	*Pinus resinosa*
Pond pine	Pond pine	Marsh pine, loblolly pine, spruce pine, bull pine.	*Pinus rigida var. serotina*
Ponderosa pine	Ponderosa pine	Western yellow pine, bull pine, Arizona white pine, western soft pine, western pine.	*Pinus ponderosa*
Shortleaf pine	Shortleaf pine [1]	Yellow pine, spruce pine, oldfield pine, Arkansas soft pine, North Carolina pine.	*Pinus echinata*
Slash pine	Slash pine [1]	Swamp pine, pitch pine	*Pinus caribaea*
Sugar pine	Sugar pine	Big pine	*Pinus lambertiana*
		REDWOOD	
Redwood	Redwood	Sequoia, coast redwood	*Sequoia sempervirens*
		SPRUCES	
Red spruce	Eastern spruce	Red spruce	*Picea rubens*
White spruce	do	White spruce	*Picea glauca*
Black spruce	do	Black spruce	*Picea mariana*
Sitka spruce	Sitka spruce	Spruce, tideland spruce, western spruce, yellow spruce, silver spruce.	*Picea sitchensis*

[1] American Lumber Standards name "Arkansas pine" includes loblolly pine and shortleaf pine; "North Carolina pine" includes loblolly pine, shortleaf pine, and Virginia pine; "Southern pine" includes longleaf pine, shortleaf pine, loblolly pine, slash pine, pond pine, and pitch pine.

ican lumber standards name corresponding to the Forest Service name used in this manual. Other names sometimes used locally but not in contracts, and botanical names are also shown.

4.021. General Classification of Softwood Lumber.—Softwood lumber is divided into three main classes—yard lumber, structural material (often referred to under the general term "timbers"), and factory and shop lumber. The following classification of softwood lumber gives the grade names used by lumber manufacturers' associations for the various classes of material under the American lumber-standards system.

- Softwood lumber
  - Yard lumber (lumber of all sizes and patterns intended for general building purposes)
    - Strips (less than 2 inches thick and less than 8 inches wide)
    - Boards (less than 2 inches thick and 8 or more inches wide)
      - *Grades*: A, B, C, D, No. 1, No. 2, No. 3, No. 4, No. 5
    - Dimension (2 inches to but not including 5 inches thick and of any width)
    - Timbers (5 inches or more in least diameter)
      - No. 1, No. 2, No. 3
  - Structural lumber (lumber 2 or more inches thick and 4 or more inches wide, intended for use where working stresses are required)
    - Beams and stringers (pieces of rectangular cross section 5 or more inches thick and 8 or more inches wide)
    - Posts and timbers (pieces of square or approximately square cross section 5 by 5 inches and larger)
    - Joists and planks (lumber from 2 but not including 5 inches thick and 4 or more inches wide)
  - Factory and shop lumber (lumber intended to be cut up for use in further manufacture)
    - Factory plank graded for door, sash, and other cuttings 1 inch to 4 inches thick and 5 inches and over wide
      - Factory clears, upper grades
        - Nos. 1 and 2 clear factory
        - No. 3 clear factory
      - Shop, lower grades
        - No. 1 shop
        - No. 2 shop
        - No. 3 shop
    - Shop lumber graded for general cut up purposes
      - 1 inch thick (northern and western pine and Pacific coast woods)
        - Select
        - Shop
      - All thicknesses (cypress, redwood and southern pine)
        - Tank and boat stock
        - Firsts and Seconds
        - Selects
        - No. 1 shop
        - No. 2 shop
        - Box

4.0210. Yard Lumber—Size Standards.—Standard lengths are multiples of 2 feet except for the following odd lengths which are allowed:

Cross section	*Feet*
2 by 4 inches, 6 by 8 inches	9 and 11
2 by 8 inches	13
2 by 10 inches	13 and 15

The thickness and widths of various yard-lumber products in three conditions—rough green, rough dry, and dressed—are given in table 4–4. In commercial practice the dressed dimensions are considered minimums and some association rules provide for thicker and wider sizes than American lumber standards.

4.0211. Yard Lumber—Grade Standards.—Ordinary building lumber is graded by lumber manufacturers' associations as finish items, select A, B, C, and D; Boards No. 1, No. 2, No. 3, No. 4, and No. 5; and dimension, No. 1 dimension, No. 2 dimension, and No. 3 dimensions. The general requirements of these grades as used by lumber manufacturers' associations under the American lumber standards system promulgated by the U. S. Department of Commerce through industry-wide agreement are as follows:

- Total products of a typical log arranged in series according to quality as determined by appearance
  - Finish items (lumber of good appearance and finishing)
    - Suitable for natural finishes
      - Grade A (practically free from defects)
      - Grade B ((allows a few small defects or blemishes)
    - Suitable for paint finishes
      - Grade C (allows a limited number of small defects or blemishes that can be covered with paint)
      - Grade D (allows any number of defects or blemishes which do not detract from the appearance of the finish, especially when painted)
  - Boards (lumber containing defects or blemishes which detract from the appearance of the finish but suitable for general-utility and construction purposes)
    - Lumber suitable for use without waste
      - No. 1 boards (sound and tight-knotted stock; size of defects and blemishes limited; may be considered water-tight lumber)
      - No. 2 boards (allows large and coarse defects; may be considered grain-tight lumber)
    - Lumber permitting waste
      - No. 3 boards (allows larger and coarser defects than No. 2 and occasional knotholes)
      - No. 4 boards (low-quality lumber admitting the coarsest defects, such as decay and holes)
      - No. 5 boards (must hold together under ordinary handling)

TABLE 4–4.—*Summary of American standard thicknesses and widths [1] for softwood yard lumber, including finish, boards, dimension, and heavy joist, siding, flooring, ceiling, partition, shiplap, and dressed and matched lumber*

Product	Rough green or nominal sizes (board measure): Thickness	Rough green or nominal sizes (board measure): Width	Minimum rough-dry dimensions: Thickness: Standard yard [2]	Minimum rough-dry dimensions: Thickness: Standard industrial	Minimum rough-dry dimensions: Width	Dressed dimensions: Thickness: Standard yard	Dressed dimensions: Thickness: Standard industrial	Dressed dimensions: Width (face when worked)
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
	-	3	-	-	2 3/4	5/16	-	2 5/8
	-	4	-	-	3 5/8	7/16	-	[3] 5 1/2
	-	5	-	-	4 5/8	9/16	-	[3] 4 1/2
	-	6	-	-	5 5/8	11/16	-	[3] 5 1/2
	1	7	29/32	[4] 30/32	6 5/8	25/32	26/32	6 1/2
Finish	1 1/4	8	1 3/16	-	7 3/8	1 1/16	-	[3] 7 1/4
	1 1/2	9	1 7/16	-	8 3/8	1 5/16	-	[3] 8 1/4
	1 3/4	10	1 9/16	-	9 3/8	1 7/16	-	[3] 9 1/4
	2	11	1 6/8	[2] 1 7/8	10 3/8	1 5/8	1 6/8	[3] 10 1/4
	2 1/2	12	2 1/4	-	11 3/8	2 1/8	-	[3] 11 1/4
	3	-	2 6/8	-	-	2 5/8	-	-
	1	3	29/32	[4] 30/32	2 3/4	25/32	25/32	2 5/8
	1 1/4	4	1 3/16	-	3 3/4	1 1/16	-	3 5/8
	1 1/2	5	1 7/16	-	4 3/4	1 5/16	-	4 5/8
	-	6	-	-	5 3/4	-	-	5 5/8
Common boards and strips	-	7	-	-	6 3/4	-	-	6 5/8
	-	8	-	-	7 5/8	-	-	7 1/2
	-	9	-	-	8 5/8	-	-	8 1/2
	-	10	-	-	9 5/8	-	-	9 1/2
	-	11	-	-	10 5/8	-	-	10 1/2
	-	12	-	-	11 5/8	-	-	11 1/2
	-	4	-	-	-	[5] 7/16 by 3/16	-	3 1/2
Bevel siding	-	5	-	-	-	10/16 by 3/16	-	4 1/2
	-	6	-	-	-	-	-	5 1/2
	-	8	-	-	-	[5] 7/16 by 3/16	-	7 1/4
Wide bevel siding	-	10	-	-	-	9/16 by 3/16	-	9 1/4
	-	12	-	-	-	11/16 by 3/16	-	11 1/4
	-	4	-	-	-	9/16	-	3 1/8
Rustic and drop siding (shiplapped)	-	5	-	-	-	3/4	-	4 1/8
	-	6	-	-	-	-	-	5 1/16
	-	8	-	-	-	-	-	6 7/8

For footnote see end of table.

TABLE 4-4.—*Summary of American standard thicknesses and widths* [1] *for softwood yard lumber, including finish, boards, dimension, and heavy joist, siding, ceiling, partition, shiplap, and dressed and matched lumber*—Continued

Product	Rough green or nominal sizes (board measure)		Minimum rough-dry dimensions			Dressed dimensions		
	Thickness	Width	Thickness: Standard yard [2]	Thickness: Standard industrial	Width	Thickness: Standard yard	Thickness: Standard industrial	Width (face when worked)
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Rustic and drop siding (D. & M.)	-------	4	-------	-------	-------	9/16	-------	3 1/4
	-------	5	-------	-------	-------	3/4	-------	4 1/4
	-------	6	-------	-------	-------	-------	-------	5 3/16
	-------	8	-------	-------	-------	-------	-------	7
Flooring	-------	2	-------	-------	-------	5/16	-------	1 1/2
	-------	3	-------	-------	-------	7/16	-------	2 3/8
	-------	4	-------	-------	-------	9/16	-------	3 1/4
	1	5	-------	-------	-------	25/32	-------	4 1/4
	1 1/4	6	-------	-------	-------	1 1/16	-------	5 3/16
	1 1/2	-------	-------	-------	-------	1 5/16	-------	-------
Ceiling	-------	3	-------	-------	-------	5/16	-------	2 3/8
	-------	4	-------	-------	-------	7/16	-------	3 1/4
	-------	5	-------	-------	-------	9/16	-------	4 1/4
	-------	6	-------	-------	-------	11/16	-------	5 3/16
Partition	-------	3	-------	-------	-------	3/4	-------	2 3/8
	-------	4	-------	-------	-------	-------	-------	3 1/4
	-------	5	-------	-------	-------	-------	-------	4 1/4
	-------	6	-------	-------	-------	-------	-------	5 3/16
Shiplap	1	4	-------	-------	-------	25/32	-------	3 1/8
	-------	6	-------	-------	-------	-------	-------	5 1/8
	-------	8	-------	-------	-------	-------	-------	7 1/8
	-------	10	-------	-------	-------	-------	-------	9 1/8
	-------	12	-------	-------	-------	-------	-------	11 1/8
Dressed and matched	1	4	-------	-------	-------	25/32	-------	3 1/4
	1 1/4	6	-------	-------	-------	1 1/16	-------	5 1/4
	1 1/2	8	-------	-------	-------	1 5/16	-------	7 1/4
	-------	10	-------	-------	-------	-------	-------	9 1/4
	-------	12	-------	-------	-------	-------	-------	11 1/4
Dimension and heavy joist	2	2	1 3/4	[2] 1 7/8	1 3/4	1 5/8	1 3/4	1 5/8
	2 1/2	4	2 1/4	-------	3 3/4	2 1/8	-------	3 5/8
	3	6	2 3/4	-------	5 3/4	2 5/8	-------	5 5/8
	4	8	3 3/4	-------	7 5/8	3 5/8	-------	7 1/2
	-------	10	-------	-------	9 5/8	-------	-------	9 1/2
	-------	12	-------	-------	11 5/8	-------	-------	11 1/2

[1] The thicknesses apply to all widths and the widths to all thicknesses, with the following exceptions: In tongue-and-groove flooring and in tongue-and-groove and shiplapped ceiling 5/16, 7/16, and 9/16 inch thick, board measure, the tongue or lap shall be 3/16 inch wide, with over-all widths 3/16 inch wider than the face widths shown above. In all other patterned material, 11/16, 3/4, 1, 1 1/4, and 1 1/2 inches thick, board measure, the tongue shall be 1/4 inch wide in tongue-and-groove lumber and the lap 3/8 inch wide in shiplapped lumber with the over-all widths 1/4 and 3/8 inch wider, respectively, than the face widths shown above. In patterned material 2 inches and thicker, board measure the tongue shall be 3/8 inch wide in tongued and grooved (D. & M.) lumber and the lap 1/2 inch wide in shiplapped lumber, with the over-all width 3/8 inch and 1/2 inch wider, respectively, than the face widths shown above.

[2] 20 percent may be 1/32 inch scant.

[3] Based on kiln-dried lumber.

[4] 10 percent may be 1/32 inch scant.

[5] Minimum.

4.02110. Finish or Select Lumber—Grade Qualities.—Select grades [6] provide for good appearance and finishing qualities. Grades A and B are suitable for natural, and grades C and D for paint finishes. In a few species where there is a pronounced difference in color between heartwood and sapwood and where high natural resistance to decay is required, a grade of clear heart is available.

Seasoning faults, such as check, either in flat surfaces or at the ends of boards, are among the more frequent imperfections in the select grades. Imperfect seasoning often causes a low-

[6] Detailed descriptions, photographs, and use recommendations for the various grades are given in pamphlets entitled "Lumber Grade-Use Guide," issued by the National Lumber Manufacturers' Association, Washington, D. C.

ering of grade, but the number of such occurrences is considerably reduced at plants of careful manufacturers.

Pitch pocket is a relatively common feature in the select grades of several species but occurs less frequently than knots in all the important species except one.

Among the other defects that are factors in the select grades are stain and chipped and torn grain.

Grade A is practically clear wood. It is manufactured for such items as finish, flooring, ceiling, partition, and siding. A large number of manufacturers do not segregate the grade even in these items, and some of the lumber associations do not recognize the quality as a separate grade. Where the grade is not segregated it is combined with B grade and sold as B and Better. Grade A lumber is used almost entirely for interior and exterior trim and for flooring. The demand is small and confined largely to high-class construction, such as office buildings and the higher cost residences.

Grade B allows a few small imperfections. In practice these small imperfections mainly take the form of minor skips in manufacture and small checks or stain due to seasoning, and, depending on the species, small pitch areas, pin knots, or the like. Grade B and Better is the highest quality segregated in a number of woods. In construction it is the grade most commonly used for high-class interior and exterior trim, especially where these are to receive a natural finish. It is the principal grade used for flooring in homes.

Grade C is classified as allowing a limited number of small imperfections that can be easily covered with paint. Specifically, the number of these per board averages about twice that of B and Better. Grace C lumber is especially adapted to use where a high-class paint finish is desired. It is, therefore, popular for cornice, and other exteriors of dwellings, porch flooring, porch columns, trim for bedrooms and kitchens, built-in kitchen fixtures, and siding for the better class of structures. It is used to some extent for natural finishes in medium- and low-priced dwellings.

Grade D is classified as allowing any number of surface imperfections that do not detract from the appearance of the finish when painted. In practice the number of such surface defects per board averages 3 to 5 times as many as in B and Better. Grade D is used in construction for the same uses as grade C. It goes into moderate- or low-priced houses, furnishing a medium-priced lumber for casing, cornice work, shelving, and built-in fixtures that are to be painted. It is also used extensively for millwork and molding.

Depending on the species, the highest commercially recognized grade may be C and Better, or D and Better, but no such combination of grades except B and Better is recognized in American lumber standards unless the actual proportions in the mixed grade are specified in the invoice.

4.0211. Boards—Grade Qualities.—Grades of boards contain defects that detract from the appearance of the finish but are suitable for general utility and construction purposes. The differences between the various board grades are due to the size and soundness more than to the number of such defects as knots, pitch, and the like. No. 1 and No. 2 boards are for use without waste. No. 3, No. 4, and No. 5 boards permit a limited amount of waste.

No. 1 boards are described in the basic classification as sound and tight-knotted stock in which the size of the knot is limited. The provisions further state that it may be considered watertight lumber. In most species practically all boards in the grade contain knots, although in some species pitch is the predominant characteristic of the grade. The size of the knots varies with the species. From one-half to three-fourths of the knots are usually intergrown; the remaining knots are encased, a small proportion of which are unsound, broken, or checked.

This grade is used for siding, cornices, and other exterior trim in medium- and low-priced homes, and for sheathing and roof boards in the more expensive type of buildings. Its use for interior trim is confined to cheaper construction and where high-class paint finishes are not required. In this grade it is difficult to conceal the knots entirely with paint. It is used extensively for door and window frames and for backing and concealed parts of furniture and fixtures.

No. 2 boards are classified as allowing large and coarse defects. In practice a small amount of through-shake, through-pitch pockets, and decay is permitted in the grade. The proportion

of large knots is greater than in No. 1, and whereas 33 to 75 percent of the knots are intergrown, 10 percent or more are usually unsound, loose, or otherwise partially open. Occasional spike knots (formed by cutting a branch lengthwise rather than crosswise) are found. Some commercial grading rules allow knot holes in the grade, provided they are strictly limited as to size and number. No. 2 boards are used primarily as coverage where the wood is not painted or otherwise finished. Subfloors, sheathing, and concrete forms are typical uses for the grade. The popular type of knotty finish is largely selected from this grade.

No. 3 boards are classified as allowing larger and coarser knots than No. 2 boards and also occasional knot holes. A larger portion of large knots and increased amounts of shake, decay, and holes distinguish No. 3 boards from No. 2 boards. No. 3 boards are used in construction for concrete forms, sheathing, subfloors, roof boards, and temporary construction. They fill a demand from builders of less exacting types of buildings for a cheaper material than No. 2.

Grades No. 4 and No. 5 boards are provided for in American lumber standards but are not produced in some species. No. 4 is described in the basic-grade classification as a low-quality lumber admitting of the coarsest defects, such as decay and holes. The only requirement as to the quality of No. 5 lumber is that it holds together under ordinary handling.

No. 4 boards are not graded for use as a whole. They are used for sheathing, subfloors, and roof boards in the cheaper types of construction. The use of the grade for these purposes involves some additional labor and a small amount of waste in cutting out defective material.

No. 5 boards are seldom shipped far from the mill and are, therefore, not commonly available at retail yards in nonforested regions. They are used for rough and temporary coverage of buildings.

In cases where commercial grading rules divide the entire range of boards into three grades instead of five grades as in American lumber standards, the first or highest grade of the three-grade division will normally contain material with a wider range in quality than the first grade of the five-grade division, and the third or lowest grade of the three-grade division will contain lower-quality material than the third grade of the five-grade division. This fact and the differences in inherent properties of different species make it impossible to consider the common grades of corresponding name for the different woods as interchangeable in use.

In most species one-third to two-thirds of the knots in the grades of boards below finish are intergrown, whereas in the select grades encases comprise a larger proportion of the total. Intergrown knots may check if large, but they do not loosen or drop out, as they are integral parts of the wood. A large number of the encased knots remain tight in some woods, but in others many of them loosen. The loosening becomes more pronounced in large knots and as the lumber becomes drier.

4.02112. Dimension.—Dimension is lumber that ranges in thickness from 2 to, but not including, 5 inches, and of any width. It is manufactured only in Nos. 1, 2, and 3 dimension grades.

Dimension is graded primarily on its strength, stiffness, and straightness. Grading is based principally on the requirements of framing for buildings. The dimension grades are best adapted to use where stiffness is the controlling factor, as in joists and studs, or where the size of the member is determined by common building practice rather than specially designed to carry definite live and dead loads.[7] Rafters of dwelling houses are good examples of members whose size is generally determined by common practice rather than by special design.

No. 1 dimension is a sound grade allowing knots limited in size depending on the size of the piece. Features, such as pitch, torn grain, checks, and stain, that do not materially affect the strength of the piece are not limited. Wane is limited to provide good nailing on one side and two edges. The grade is for joists, rafters, scaffolding, light framing, and for the less exacting items in heavier framing.

No. 2 dimension admits large, coarse, unsound knots, warped pieces, certain types of decay, and has fair nailing edges and other defects that will not weaken the piece to an

[7] Where members are designed to carry heavy loads and where strength rather than stiffness is the controlling factor, the structural grades of joists and plank should be used in preference to the dimension grades, as the structural grades are more scientifically graded and definite working stresses can be assigned to them.

extent that will render it unfit for use as a whole. It is used in construction for joists and rafters in medium-priced light-frame construction and for plates, sills, studding, and other vertical load-bearing members in high-priced light construction.

No. 3 dimension is described generally as including all pieces falling below the grade of No. 2 that are suitable for use in cheap building. It admits all defects of No. 2 without limitations on size or number providing they do not seriously affect the utility of the piece or involve waste of more than 25 percent in not more than one-third of the pieces. It is used for studding in low-priced and temporary light-frame construction. In small buildings where the members are short, No. 3 dimension may be cut and used with considerable economy.

4.0212. Structural Material—Size Standards.—Structural material is not dealt with in detail in this manual because it is of less interest to the prefabricator than are most other types of lumber. It is divided into three classes: joist and plank (2 inches to 4 inches thick by 4 inches or wider); beams and stringers (5 inches and thicker by 4 inches and wider); and posts and timbers (5 inches by 5 inches and larger). Standard lengths in all three classes are in multiples of 2 feet, with a few exceptions.

4.0213. Structural Material—Grade Standards.—Structural material is graded on a basis of strength and is intended for use where working stresses are required.

4.0214. Factory and Shop Lumber—Size Standards.—Standard lengths of factory and shop lumber are 6 feet and over in multiples of 1 foot, except the box grade of shop lumber, in which the standard lengths are 4 feet and over. Standard widths are 5 inches and over, and are usually shipped in random widths. Standard thicknesses are given in table 4–5.

TABLE 4–5.—*Standard thicknesses of factory and shop lumber*

Nominal thickness	Finished thicknesses SIS or S2S	Nominal thickness	Finished thicknesses SIS or S2S
Inches	*Inches*	*Inches*	*Inches*
1	$\frac{25}{32}$ or $\frac{26}{32}$	$2\frac{1}{4}$	$2\frac{1}{8}$
$1\frac{1}{4}$	$1\frac{5}{32}$	$2\frac{1}{2}$	$2\frac{3}{8}$
$1\frac{1}{2}$	$1\frac{13}{32}$	3	$2\frac{6}{8}$
2	$1\frac{26}{32}$	4	$3\frac{6}{8}$

4.0215. Factory and Shop Lumber—Grade Standards.—Factory and shop lumber is divided into two classes from the standpoint of use—factory plank and shop lumber—each of which has a different set of grades. These grades are based on the percentage of the area of each board or plank that will furnish cuttings of specified sizes and qualities except in the upper grades of shop lumber of all thicknesses.

Factory plank is $1\frac{1}{4}$ inches or more in thickness and is used largely for door and sash cuttings. The No. 1 cuttings referred to in the following grade requirements for factory plank must be free of defects on both sides. The No. 2 cuttings may contain any one of the following seven defects: a limited amount of blue or brown stain, a small tight knot, a small pitch pocket or streak, small season checks, and slightly torn grain. The cuttings are of various lengths and widths, depending on the door (or sash) parts for which they are used.

The basic grade classifications for softwood factory plank (American lumber standards) are as shown on the following page.

Because of the small volume of shop lumber that is made and the special uses to which it is largely put, shop lumber is of little interest to the prefabricator.

4.03. Grade-marked Lumber and Moisture Content Provisions.—Grade-marked and trade-marked lumber for some time past has been available in some species and items. Each piece of such lumber typically is stamped with its proper grade, with a number identifying the mill where it was made, and with the mark of the lumber association promulgating the grading rules. The grade designation stamped on a board indicates the quality at the time the piece was graded. Subsequent exposure to unfavorable storage conditions, improper drying, or careless handling may cause the material to fall below its original grade.

Lumber may be purchased under moisture content provisions. The allowable moisture content is lower in the thinner material and in the select grades. In one specification for kiln-dried 4/4-inch and 5/4-inch lumber of C and Better quality, for instance, the moisture content must not exceed 12 percent in 90 percent of the pieces, and the remainder must not exceed 15 percent moisture content. For thicker select lumber and for kiln-dried boards and dimension the allow-

- Factory plank (factory lumber graded with reference to its use for doors, sash, and other cuttings)
  - Factory clears (upper grades of factory plank containing a high percentage of best-quality cuttings)
    - Nos. 1 and 2 clear factory (lumber practically clear in wide sizes, to contain not less than 85 percent of no. 1 door cuttings, not including pieces with over two muntins, or muntins only)
    - No. 3 clear factory (lumber containing not less than 70 percent of no. 1 door cuttings, not including pieces with over two muntins, or muntins only)
  - Shop (lower grades of factory plank yielding smaller percentages in smaller and lower quality cuttings)
    - No. 1 shop (lumber of high quality factory grade containing not less than 50 percent of no. 1 door cuttings, allowing, if necessary, one no. 2 stile in any piece, but no pieces with over two muntins, or muntins only)
    - No. 2 shop (lumber containing not less than 25 percent of no. 1 door cuttings, or 40 percent of no. 2 door cuttings, or 33 1/3 percent of mixed door cuttings)
    - No. 3 shop (lumber of a shop type below the grade of no. 2 shop and better than box lumber)

able moisture-content values run up to 15 percent for 90 percent of the pieces and 18 percent for the remainder. Specifications for air-dried lumber are expressed similarly but the allowable moisture-content values are higher, ranging from 16 percent and 19 percent for 4/4-inch C and Better up to 19 percent and 22 percent for 8/4-inch dimension.

4.1. GRADES AND SIZES OF PLYWOOD.—Plywood for prefabricated house construction is produced in flat panels, generally 4 by 8 feet in size. Some manufacturers produce plywood in 10-, 12-, or 16-foot lengths, either cutting veneer in those lengths or scarf jointing short plywood panels together. It is highly desirable to design for the use of 4- by 8-foot panels wherever possible, because this size is most readily available; the larger sizes are often difficult to obtain in sufficient quantities and are more costly on a square foot basis. Long plywood panels are a specialty product, and for this reason builders wishing to utilize them should make certain of a continuing source of supply before going into production.

Broadly speaking, two classes of plywood are used in house construction, softwood and hardwood plywood. The bulk of softwood plywood is made of Douglas-fir, with a small proportion consisting of Western hemlock and other species. Hardwood plywood is made of a large variety of species.

4.10. Types and Grades of Plywood.—The types and grades of plywood in general use for housing in general conform to commercial standards established by the National Bureau of Standards. Separate commercial standards cover Douglas-fir, Western hemlock, and hardwood plywood.

4.100. Douglas-fir Plywood.—Douglas-fir plywood, under Commercial Standard CS 45–45, is of two types, moisture-resistant and exterior. Moisture-resistant plywood, often called "interior" plywood, comes in six grades and the exterior type in eight grades. Exterior plywood is made by hot pressing, while moisture-resistant plywood may be either hot or cold-pressed. The two types differ principally in the kind of glue used. Moisture-resistant plywood is made with protein glues, such as soybean and casein; casein glue is often mixed with soybean glue to improve the moisture resistance of the latter. Highly extended phenolic-resin glues are also used to make moisture-resistant plywood. Exterior-type plywood is generally made of hot-setting phenolic-resin glue, one of the most highly water-resistant types of adhesives available.

4.1000. Moisture-resistant Grades.—Commercial Standard CS 45–45 requires that moisture-resistant Douglas-fir plywood be capable of retaining its original form and practically all its original strength when occasionally subjected

to thorough wetting and subsequent normal drying, as well as to occasional condensation moisture or leakage. Grades of moisture-resistant plywood are:

1. **Sound 2 Sides (SO2S).**—Each face shall be of one or more pieces of firm, smoothly cut veneer. When of more than one piece, it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, pitch pockets, and other open defects. Streaks, discolorations, sapwood, shims, and neatly made patches shall be admitted. This grade shall present a smooth surface suitable for painting.

2. **Sound 1 Side (SO1S).**—The face shall be of one or more pieces of firm smoothly cut veneer. When of more than one piece, it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, pitch pockets, and other open defects. Streaks, discolorations, sapwood, shims, and neatly made patches shall be admitted. The face shall present a smooth surface suitable for painting. The back shall present a solid surface with all knots in excess of 1 inch patched and with the following permitted: Not more than six knotholes or borer holes five-eighths inch or less in greater dimension, splits one-eighth inch or less in width and pitch pockets not in excess of 1 inch wide or 3 inches long or that do not penetrate through veneer to the glue line. There may be any number of patches and plugs in the back.

3. **Wallboard (WB).**—This is a three-ply board of ¼-inch or ⅜-inch sanded, or five-ply ½-inch sanded thickness, made only in standard wallboard sizes, the face of which shall be of one or more pieces of firm, smoothly cut veneer. When of more than one piece it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, pitch pockets, and other open defects. Streaks, discolorations, sapwood, shims, and neatly made patches shall be admitted. The face on this grade shall present a smooth surface suitable for painting. The back shall contain knotholes or pitch pockets, splits, and other defects in number and size that will not seriously affect the strength or serviceability of the panel and which cannot reasonably and economically be repaired to make a sound face. All Wallboard panels shall be so designated by grade marking each panel.

4. **Sheathing (SH) (Unsanded).**—An unsanded plywood made only in the following sizes: Thicknesses 5/16-inch and ⅜-inch three-ply; ½-inch and ⅝-inch three or five-ply; widths 36 and 48 inches; length 96 inches. The face shall present a solid surface except that the following will be permitted: (a) Not more than 10 knotholes none of which shall exceed 1½ inches with not more than 5 exceeding three-fourths inch in greatest dimension; (b) no group of knotholes within any 12-inch diameter circle shall have an aggregate greatest dimension of more than 3 inches; (c) no splits wider than one-eighth inch; nor any type of borer holes longer than 1 inch; nor open pitch pockets more than 1 inch wide. There may be any number of patches and plugs in the face, but the face may not be of such quality that, if sanded, it will pass for a Wallboard face. No belt sanding is permissible. The back shall be at least equal in quality to a Wallboard grade back. No tape shall be permitted in the glue line. All sheathing panels shall be scored or marked for nailing to conform to standard spacing of lumber studding.

5. **Industrial (Unsanded).**—Faces of panels shall be free from knotholes. Faces shall also be free from any type of borer holes more than five-eighths inch in greatest dimension and open pitch pockets more than 1 inch wide. Tight knots, checks, plugs, patches, and shims shall be admitted in either face. Core and crossbands shall be of firm stock but shall contain no knotholes greater than 1¼ inches in any dimension.

6. **Concrete-form Plywood.**—Concrete-form plywood shall be built up of three or five thicknesses of veneer, of which the two outside plies are at least one-eighth inch thick before sanding, except for plywood one-fourth inch in thickness. An occasional knothole is permissible in the center or core of five-ply panels only, but no knotholes are permitted in crossbanding. Appearance of faces shall be similar to that of "Sound 2 Sides" grade. The bonding agent used shall be especially prepared for this purpose and be very highly water-resistant. All concrete-form plywood shall be so designated by grade marking each panel on the face. Concrete-form plywood shall be edge-sealed, and have the faces mill-oiled unless the order specifically states not to oil.

4.1001. Exterior Grades.—Exterior-type plywood must be suitable for permanent exterior use and, as such, must be capable of resisting repeated wetting and drying and other hazards of climate and weather without changing shape or losing its strength. Core gaps that impair its strength and serviceability are not permitted. Maximum thickness of veneer is limited to five-sixteenths inch. The eight grades of exterior plywood described in CS 45–45 are:

1. Marine Exterior.—This is a special exterior grade of plywood intend for marine use.

2. Good 2 Sides Exterior (G2S-Ext.).—Each face shall be of a single piece of smoothly cut veneer of 100 percent heartwood, free from knots, splits, pitch pockets, and other open defects. The face shall be a yellow or pinkish color without stain. Shims that occur only at the ends of panels and inconspicuous well-matched small patches not to exceed three-eighths inch wide by 2½ inches long shall be admitted. This grade is recommended for uses where a light stain or natural finish is desired.

3. Good 1 Side Exterior (G1S-Ext.).—The face shall be equal to that described under "Good 2 Sides Exterior" grade, while the back shall be equal to the "Sound 2 Sides Exterior" grade.

4. Sound 2 Sides Exterior (SO2S-Ext.).—Each face shall be of one or more pieces of firm, smoothly cut veneer. When of more than one piece, it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, pitch pockets, and other open defects. Streaks, discolorations, sapwood, shims, and neatly made patches shall be admitted. This grade shall present a smooth surface suitable for painting.

5. Sound 1 Side Exterior (SO1S-Ext.).—The face shall be of one or more pieces of firm, smoothly cut veneer. When of more than one piece, it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, pitch pockets, and other open defects. Streaks, discolorations, sapwood, shims, and neatly made patches shall be admitted. The face on this grade shall present a smooth surface suitable for painting. The back shall contain knotholes not larger than 1 inch or pitch pockets, splits not wider than three-sixteenths inch, and other defects in number and size that will not impair the serviceability of the panel and that cannot be reasonably and economically repaired to make a sound face.

6. Sheathing Exterior (SH-Ext.) (Unsanded).—An unsanded panel, the face of which shall present a solid surface except that the following will be permitted: (a) Not more than six knotholes three-eighths inch or less in greatest dimension, (b) splits one-sixteenth inch or less in width, (c) one or two strips of paper tape. There may be any number of patches and plugs in the face but the face may not be of such quality that, if sanded, it will pass for "Sound 1 Side Exterior" grade. No belt sanding is permissible. The back shall be the same as the back described under "Sound 1 Side Exterior" grade. Exterior-type sheathing is made in 5/16-inch, ⅜-inch, ½-inch, and ⅝-inch thicknesses and in one standard panel size, 48 inches by 96 inches.

7. Industrial Exterior.—Industrial Exterior plywood shall have two solid faces made of one or more pieces. All open defects shall be repaired, except small pitch pockets, and tight splits which are one-sixteenth inch or under in width. All knotholes in the face veneer shall be patched. Panels in this grade shall be lightly "touch" sanded on both sides to remove dry tape, surplus glue, etc., but the tolerance of one thirty-second inch, as allowed for unsanded panels, shall apply.

8. Concrete-form Exterior.—Concrete-form Exterior plywood shall be the same as "Sound 2 Sides Exterior" except that faces shall be one-eighth inch thick before sanding. It is made only in ⅝-inch and ¾-inch thicknesses. All concrete-form plywood shall be so designated by grade marking each panel on the face. Concrete-form plywood shall be edge-sealed and have the faces mill-oiled unless the order specifically states not to oil.

4.1002. Size Standards.—Douglas-fir plywood standard sizes as set up in Commercial Standard CS 45–45 are given in table 4–6. Under normal production conditions before World War II, plywood manufacturers could furnish plywood in any size ordered. During the war and immediate postwar period, however, manufacturers have been limited to these standard sizes in order to facilitate plywood production.

4.1003. Grade Marking.—The grade markings shown in figure 4–1 are stamped on Douglas-fir plywood to afford a reliable means of distinguishing one grade from another. These

TABLE 4-6.—*Standard Douglas-fir plywood sizes*

Item	Width	Length	Thickness
MOISTURE-RESISTANT TYPE			
	Inches	*Inches*	*Inches*
Standard panels (S02S) (S01S)	24 30 36 48	60 72 84 96	1/8 (3-ply, sanded 2 sides) 3/16 (3-ply, sanded 2 sides) 1/4 (3-ply, sanded 2 sides) 3/8 (3-ply, sanded 2 sides) 1/2 (5-ply, sanded 2 sides) 5/8 (5-ply, sanded 2 sides) 3/4 (5-ply, sanded 2 sides)
Wallboard	48	60 72 84 96	1/4 (3-ply, sanded 2 sides) 3/8 (3-ply, sanded 2 sides) 1/2 (5-ply, sanded 2 sides)
Sheathing	36 48	96	5/16 (3-ply, unsanded) 3/8 (3-ply, unsanded) 1/2 (3- or 5-ply, unsanded) 5/8 (3- or 5-ply, unsanded)
Industrial	As ordered up to 48	As ordered up to 96	1/4 (3-ply, unsanded) 5/16 (3-ply, unsanded) 3/8 (3-ply, unsanded) 1/2 (5-ply, unsanded) 9/16 (5-ply, unsanded) 5/8 (5-ply, unsanded) 11/16 (5-ply, unsanded) 3/4 (5-ply, unsanded) 7/8 (5-ply, unsanded) 7/8 (7-ply, unsanded)
Concrete-form panels	36 48	60 72 84 96	1/4 (3-ply, sanded 2 sides) 1/2 (5-ply, sanded 2 sides) 9/16 (5-ply, sanded 2 sides) 5/8 (5-ply, sanded 2 sides) 3/4 (5-ply, sanded 2 sides)
EXTERIOR TYPE [1]			
Standard panels (Marine) (G2S-Ext.) (G1S-Ext.) (S02S-Ext.) (S01S-Ext.).	12 14 16 18 20 22 24 26 28 30 36 42 48	48 60 72 84 96	3/16 (3-ply, sanded 2 sides) 1/4 (3-ply, sanded 2 sides) 5/16 (3-ply, sanded 2 sides) 3/8 (3-ply, sanded 2 sides) 7/16 (5-ply, sanded 2 sides) 1/2 (5-ply, sanded 2 sides) 9/16 (5-ply, sanded 2 sides) 5/8 (5-ply, sanded 2 sides) 11/16 (5-ply, sanded 2 sides) 3/4 (5-ply, sanded 2 sides) 13/16 (5-ply, sanded 2 sides) 7/8 (7-ply, sanded 2 sides) 15/16 (7-ply, sanded 2 sides) 1 (7-ply, sanded 2 sides) 1 1/16 (7-ply, sanded 2 sides) 1 1/8 (7-ply, sanded 2 sides) 1 3/16 (7-ply, sanded 2 sides)
Sheathing, exterior	48	96	5/16 (3-ply, unsanded) 3/8 (3-ply, unsanded) 1/2 (3-ply, unsanded) 5/8 (3-ply, unsanded)
Industrial, exterior	As ordered	As ordered	1/4 (3-ply, unsanded) 5/16 (3-ply, unsanded) 3/8 (3-ply, unsanded) 7/16 (3-ply, unsanded) 1/2 (5-ply, unsanded) 9/16 (5-ply, unsanded) 5/8 (5-ply, unsanded) 11/16 (5-ply, unsanded) 3/4 (5-ply, unsanded) 7/8 (5-ply, unsanded)
Concrete-form panels, exterior	Same as standard panels	Same as standard panels	5/8 (3-ply, sanded 2 sides) 3/4 (5-ply, sanded 2 sides)

[1] Number of plies listed under thickness is minimum.

grade markings aid in selecting plywood for a given use in the house and help to curb waste and avoid mistakes in the plant. The markings are stamped or branded on an edge, back, or face of each plywood sheet at the factory.

FIGURE 4–1.—Standard grade marking outlines as given in Commercial Standard CS 45–45 for Douglas-fir plywood conforming to the requirements of that standard. From top to bottom, the markings apply as follows: Top, stamped or branded on one edge of standard panels of Sound 2 Sides and Sound 1 Side grades; second, stamped or branded on back of Wallboard grade panels; third, scored in parallel lines at 16-inch intervals across the face repeated at frequent intervals, and also stamped in the corner of all sheathing panels; fourth, stamped on the face of concrete-form panels; bottom, stamped or branded on the edge of all exterior-type plywood.

4.101. Western Hemlock Plywood.—As defined by Commercial Standard CS 122–45, Western hemlock plywood is of the moisture-resistant type only. Four grades are described. The faces may be of Western hemlock, noble fir, or white fir, and Douglas-fir may also be used for cores and crossbands. The moisture resistance requirement is the same as that for moisture-resistant Douglas-fir plywood. Veneer thickness of plywood one-fourth inch thick or thicker is limited to one-twelfth to three-sixteenths inch. The four grades as set forth in CS 122–45 are:

1. Sound 2 Sides (SO2S) (Sanded 2 Sides).—Each face shall be of one or more pieces of firm, smoothly cut veneer. When of more than one piece, it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, bark pockets, and other open defects. Black streaks (if not open), discolorations, sapwood, shims, and neatly made patches shall be admitted. This grade shall present a smooth surface suitable for painting.

2. Sound 1 Side (SO1S) (Sanded 2 Sides).—The face shall be of one or more pieces of firm, smoothly cut veneer. When of more than one piece, it shall be well joined and reasonably matched for grain and color at the joints. It shall be free from knots, splits, bark pockets, and other open defects. Black streaks (if not open), discolorations, sapwood, shims, and neatly made patches shall be admitted. The face shall present a smooth surface suitable for painting. The back may contain knots, knotholes not greater than 1 inch in greatest dimension, splits not wider than three-sixteenths inch, and bark pockets and other defects that will not seriously affect the strength or serviceability of the panel. There may be any number of patches and plugs in the back.

3. Sheathing (Unsanded).—The grade is made only in the following sizes: Thicknesses 5/16-inch and $\frac{3}{8}$-inch three-ply; $\frac{1}{2}$-inch and $\frac{5}{8}$-inch five-ply; width 48 inches; length 96 inches. The face may contain the following: (a) Not more than 10 knotholes, none of which shall exceed $1\frac{1}{2}$ inches with not more than five exceeding three-fourths inch in greatest dimension; (b) no group of knotholes within any 12-inch-diameter circle shall have an aggregate greatest dimension more than 3 inches; (c) no splits wider than one-eighth inch; or any type of

borer holes longer than 1 inch; or open bark pockets or other open defects more than 1 inch wide. There may be any number of patches and plugs in the face. No belt sanding is permissible. The back may contain knotholes or bark pockets, splits, and other defects in number and size that will not seriously affect the strength or serviceability of the panel. No knotholes shall be admitted greater than 2½ inches in least dimension, no splits wider than three-fourths inch at widest point, no open defects greater than 1½ inches by 4 inches or equivalent area, and no open defects which extend through two adjacent veneers at the same point.

4. Industrial (Unsanded).—Faces of panel shall be free from both knotholes and borer holes more than five-eighths inch in greatest dimension, and open bark pockets more than five-eighths inch wide. Tight knots, checks, plugs, patches, and shims shall be admitted in either face. Core and crossbands shall be of firm stock but shall contain no knotholes greater than 1¼ inches in any dimension.

4.1010. Size Standards.—Western hemlock plywood standard sizes as set up in Commercial Standard CS 122–45 are given in table 4–7.

4.1011. Grade Marking.—Figure 4–2 illustrates the grade marks stamped on all Western hemlock plywood that conforms with the requirements of Commercial Standard CS 122–45.

4.102. Hardwood Plywood.—Four types of hardwood plywoods have been established by Commercial Standard CS 35–46 (Tentative), differing on the basis of the moisture resistance of their glue bonds. Type I plywood requires a fully waterproof bond, type II a bond with high water resistance, type III a bond with low water resistance, and type IV a dry bond. Under each of these types, four grades of plywood are provided on the basis of defects permitted. Grade requirements as to defects vary according to the species of which the plywood is made.

Of the four types of hardwood plywood, only type I, fully water-proof, is suitable for exterior use in prefabricated housing. Type II has sufficient moisture resistance to withstand moderate exposure to moisture without delamination and should hence be suitable for all interior uses in dry floors, walls, and ceilings.

Table 4–7.—*Standard Western hemlock plywood sizes* [1] [2]

Grade	Width	Length	Thickness
	Inches	*Inches*	*Inch*
(S02S) (S01S)	24	60	⅛ (3-ply, sanded 2 sides)
	30	72	3/16 (3-ply, sanded 2 sides)
	36	84	¼ (3-ply, sanded 2 sides)
	48	96	⅜ (3-ply, sanded 2 sides)
		108	½ (5-ply, sanded 2 sides)
		120	⅝ (5-ply, sanded 2 sides)
		144	¾ (5-ply, sanded 2 sides)
Sheathing	48	96	5/16 (3-ply, unsanded)
			⅜ (3-ply, unsanded)
			½ (3- or 5-ply, unsanded)
			⅝ (3- or 5-ply, unsanded)
Industrial	As ordered up to 48	As ordered up to 96	¼ (3-ply, unsanded)
			5/16 (3-ply, unsanded)
			⅜ (3-ply, unsanded)
			½ (5-ply, unsanded)
			9/16 (5-ply, unsanded)
			⅝ (5-ply, unsanded)
			11/16 (5-ply, unsanded)
			¾ (5-ply, unsanded)
			⅞ (5-ply, unsanded)
			⅞ (7-ply, unsanded)

[1] A tolerance of 1/64 (0.0156) inch over or under the specified thickness shall be allowed on sanded panels and a tolerance of 1/32 (0.0312) inch on unsanded panels.

[2] A tolerance of 1/32 (0.0312) inch over or under the specified length or width shall be allowed, but all panels shall be square within ⅛ (0.1250) inch.

Type III hardwood plywood is limited in use to interior partitions.

4.1020. Size Standards.—The standard sizes and thicknesses of finished hardwood plywood, as established in Commercial Standard CS 35–46, are:

Widths: 24, 30, 36, 42, and 48 inches, with a tolerance of 1/32 inch either way.

Lengths: 48, 60, 72, 84, and 96 inches, with a tolerance of 1/32 inch either way.

Thicknesses: 1/8, 3/16, 1/4, 5/16, 3/8, 1/2, 5/8, 3/4, 13/16, 7/8, and 1 inch. Tolerance permitted for unsanded panels is 1/32 inch either way, and that for sanded panels minus 1/32 inch.

4.11. Plywood Quality Tests.

4.11. Plywood Quality Tests.—A test employed generally to determine the quality of plywood is known as the plywood shear test. This test was devised as a means of assessing the quality of the glue bonds between the plies—the critical factor in plywood of any grade.

To determine glue-joint quality, plywood specimens are cut from panels and exposed to conditions that vary according to the grade or type of plywood being tested. Exterior-type softwood plywood, for example, is exposed to more rigorous conditions than the moisture-resistant type before it is subjected to the shear test, because it is intended for more severe use conditions. Commercial Standards CS 45–45, CS 122–45, and CS 35–46 prescribe methods of selecting test specimens from shipments of plywood, exposure conditions for the various types of softwood and hardwood plywood, and the method of testing the glue joint, as well as minimum standards of quality to be maintained.

The plywood shear testing apparatus shown in figure 4–3 is in general use by the plywood industry.

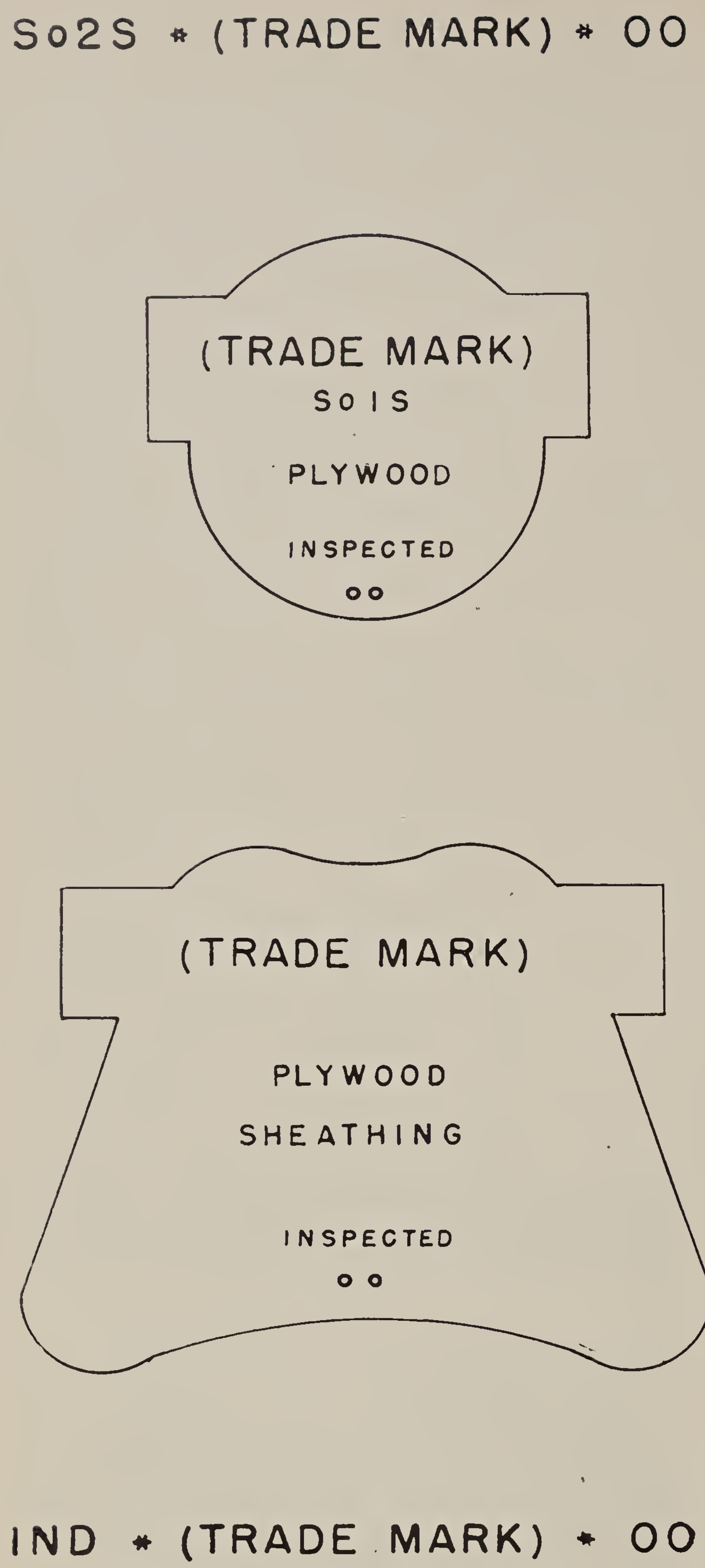


FIGURE 4–2.—Standard grade marking outlines as given in Commercial Standard CS 122–45 for use on Western hemlock plywood conforming to the requirements of that standard. From top to bottom, the markings apply as follows: Top, stamped or branded on the edge of Sound 2 Sides panels; second, stamped or branded on the back of Sound 1 Side panels; third, stamped or branded on the face of Sheathing panels; bottom, stamped or branded on the edge of Industrial panels.

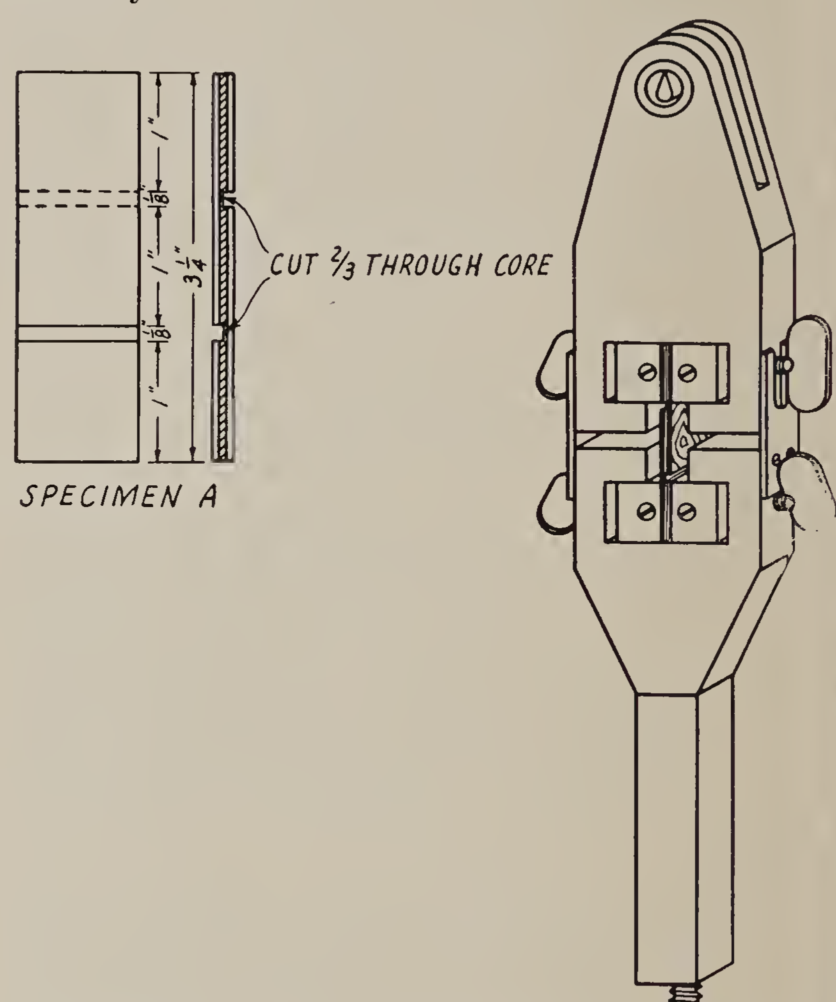


FIGURE 4–3.—Testing machine (right) and properly notched plywood shear-test specimen and grips (left) used for testing glue-joint quality in plywood. Machine registers joint strength in pounds per square inch of glue-joint area tested.

STRENGTH OF HOUSING MATERIALS

5.0. STRENGTH OF WOOD.—Strength is a general term related to all those properties that enable a material to resist forces. Generally, however, it is preferable to refer more specifically to the strength property being considered, such as strength in bending, strength in shear, or strength in compression parallel to grain. If the various species had the same relation to each other in all strength properties, a wood that excels in one property would excel in all, so that misinterpretation of the term "strength" would be unlikely. Actually, however, a species may rank higher in one strength property than in another. For example, longleaf pine averages higher than white oak in maximum crushing strength parallel to grain but lower in shear strength, so that it cannot be said that longleaf pine is "stronger" or "weaker" than white oak without specifying the kind of strength.

In many uses in housing, the serviceability of wood depends upon one or more strength properties (ch. 12). Floor joists must have adequate strength in bending, stiffness, shear, and bearing; finish and trim must be sufficiently hard to avoid marring; and window sash must have sufficient screw-holding ability to permit secure attachment of hardware as well as sufficient stiffness to prevent springing when the window is opened or closed.

The conventional house is not an engineered structure; its load-bearing members—studs, joists, rafters—are of standard sizes and are bought on a basis of size to meet certain strength and stiffness requirements for span or the load they are to carry. Actually, the conventional house has never been critically analyzed from an engineering standpoint. It is likely, however, that it is overdesigned. The strength of the sheathing, floors, and other coverings is largely ignored.

One of the primary objectives of factory fabrication is to produce a house that is designed to fulfill its function through the application of sound engineering principles that will eliminate at least some of the waste of materials that has resulted from the empirical methods of design evolved for the conventional house. Prefabricators are approaching this objective in various ways. Some are adapting truss and arch constructions to the requirements of the small house, primarily to eliminate the conventional bearing partition that bisects and governs the room size of such houses. Others have adopted the stressed-cover principle in order to utilize the inherent strength of floor, wall, ceiling, and roof covering materials. A few are experimenting with various sandwich constructions (secs. 3.44, 5.7). In all these new approaches to house design, one objective is to effect economy through more efficient utilization of materials.

The intelligent selection of species for various uses in prefabricated houses and the proper design of load-carrying members, whether trusses, stressed panels, or sandwiches, requires information on the strength properties of the various wood species. The important strength properties have been determined by means of standard tests for most domestic species and for a few foreign species. The properties determined include bending strength and stiffness, or strength and stiffness as a beam; impact strength, or ability to absorb shocks or sudden blows; compressive strength parallel to grain, or strength as a post; compressive strength perpendicular to grain, or ability to resist loads on the side grain, as at the end of a beam or joist; shearing strength; hardness, or resistance to indentation; cleavage, or resistance to splitting; and tensile strength perpendicular to grain. These strength properties, as determined by means of standard tests on green wood and on wood at 12 percent moisture content, are shown in table 5–1 for a number of species commonly used in housing.

The values of table 5–1 are averages of the strength of clear wood (free from defects) for the various species and are determined under laboratory conditions (*5–8*). Before they can be used in design, they must be adjusted to take

TABLE 5-1.—*Strength properties of a number of housing woods tested in a green condition and at 12 percent moisture content. (Results of tests on small,[1] clear specimens)*

Species	Moisture content	Specific gravity, oven-dry, based on volume—		Static bending					Impact bending		Compression parallel to grain		Compression perpendicular to grain—fiber stress at proportional limit	Shear parallel to grain—maximum shearing strength	Hardness: Load required to embed a 0.444 inch ball to ½ its diameter		Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
		At test	When oven-dry	Fiber stress at proportional limit	Modulus of— Rupture	Modulus of— Elasticity	Work to— Proportional limit	Work to— Maximum load	Fiber stress at proportional limit	Height of drop causing complete failure (50-lb. hammer)	Fiber stress at proportional limit	Maximum crushing strength			End	Side		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	Percent			P.s.i.	P.s.i.	1,000 P.s.i.	In.-lb. per cu. in.	In.-lb. per cu. in.	P.s.i.	Inches	P.s.i.	P.s.i.	P.s.i.	P.s.i.	Pounds	Pounds	Lb. per in. of width	P.s.i.
HARDWOODS																		
Ash, black	85	0.45	0.53	2,600	6,000	1,040	0.41	12.1	--------	33	1,690	2,300	430	860	590	520	280	490
	12	.49	------	7,200	12,600	1,600	1.57	14.9	--------	35	4,520	5,970	940	1,570	1,150	850	380	700
Ash, commercial white [2]	43	.54	.61	5,300	9,500	1,400	1.14	14.7	12,800	37	3,360	4,060	860	1,350	1,010	940	342	575
	12	.58	------	8,900	14,600	1,680	2.68	15.6	17,000	40	5,580	7,280	1,510	1,920	1,680	1,260	442	783
Beech, American	54	.56	.67	4,300	8,600	1,380	.85	11.9	11,500	43	2,550	3,550	670	1,290	970	850	410	720
	12	.64	------	8,700	14,900	1,720	2.63	15.1	16,000	41	4,880	7,300	1,250	2,010	1,590	1,300	490	1,010
Basswood	105	.32	.40	2,700	5,000	1,040	.40	5.3	6,300	16	1,690	2,220	210	600	290	250	150	280
	12	.37	------	5,900	8,700	1,460	1.37	7.2	9,800	16	3,800	4,730	450	990	520	410	230	350
Birch, yellow and sweet	62	.57	.68	4,400	8,700	1,560	.79	15.9	11,100	48	2,640	3,510	550	1,160	910	850	285	430
	12	.63	------	10,100	16,700	2,070	2.83	19.8	20,000	52	6,200	8,310	1,250	2,020	1,660	1,340	580	935
Chestnut, American	122	.40	.45	3,100	5,600	930	.59	7.0	7,900	24	2,080	2,470	380	800	530	420	240	440
	12	.43	------	6,100	8,600	1,230	1.78	6.5	10,700	19	3,780	5,320	760	1,080	720	540	250	460
Cottonwood, Eastern	111	.37	.43	2,900	5,300	1,010	.49	7.3	7,200	21	1,740	2,280	240	680	380	340	220	410
	12	.40	------	5,700	8,500	1,370	1.39	7.4	7,300	20	3,490	4,910	470	930	580	430	270	580
Cottonwood, Northern black	132	.32	.37	2,900	4,800	1,070	.44	5.0	6,800	20	1,760	2,160	200	600	280	250	170	270
	12	.35	------	5,300	8,300	1,260	1.25	6.7	9,800	22	3,270	4,420	370	1,020	540	350	220	330
Cucumbertree	80	.44	.52	4,200	7,400	1,560	.66	10.0	9,300	30	2,810	3,140	410	990	600	520	260	440
	12	.48	------	8,000	12,300	1,820	1.98	12.2	14,700	35	4,840	6,310	710	1,340	950	700	290	660
Elm, American	89	.46	.55	3,900	7,200	1,110	.81	11.8	--------	38	1,920	2,910	440	1,000	680	------	------	590
	12	.50	------	7,600	11,800	1,340	2.53	13.0	--------	39	4,030	5,520	850	1,510	1,110	------	------	660
Elm, rock	48	.57	.66	4,600	9,500	1,190	1.05	19.8	--------	54	2,970	3,780	750	1,270	980	------	------	------
	12	.63	------	8,000	14,800	1,540	2.45	19.2	--------	56	4,700	7,050	1,520	1,920	1,510	------	------	------
Elm, slippery	85	.48	.57	4,000	8,000	1,230	.82	15.4	9,200	47	2,790	3,320	510	1,110	750	660	380	640
	12	.53	------	7,700	13,000	1,490	2.35	16.9	15,300	45	4,760	6,360	1,010	1,630	1,120	860	340	530
Hackberry and sugarberry	64	.48	.55	3,050	6,550	880	.68	13.3	8,050	40	2,030	2,725	535	1,060	800	720	365	645
	12	.52	------	6,050	10,700	1,165	1.95	12.0	12,650	40	3,840	5,530	1,170	1,435	1,195	920	355	580
Magnolia, Southern	105	.46	.53	3,600	6,800	1,110	.67	15.4	8,880	54	2,160	2,700	570	1,040	780	740	340	610
	12	.50	------	6,800	11,200	1,400	1.90	12.8	13,600	29	3,420	5,460	1,060	1,530	1,280	1,020	430	740
Maple, bigleaf	72	.44	.51	4,400	7,400	1,100	1.02	8.7	8,500	23	2,510	3,240	550	1,110	760	628	320	600
	12	.48	------	6,600	10,700	1,450	1.66	7.8	--------	28	4,790	5,950	930	1,730	1,330	850	400	540
Maple, sugar and black (hard)	62	.54	.65	4,600	8,650	1,440	.86	13.0	11,200	44	2,825	3,645	770	1,295	1,005	905	[3] 430	[3] 720
	12	.60	------	8,900	14,550	1,725	2.58	14.5	17,050	40	4,995	7,255	1,630	2,075	1,770	1,315	[3] 420	[3] 670
Maple, silver and red (soft)	64	.46	.53	3,450	8,650	1,165	.66	11.2	[4] 6,800	30	2,145	2,885	480	1,100	725	[4] 590	295	[4] 560
	12	.50	------	7,450	11,150	1,390	2.37	10.4	[4] 12,400	28	4,505	5,880	1,075	1,665	1,285	[4] 700	420	[4] 500
Oak, red [5]	80	.57	.68	4,400	8,500	1,360	.85	12.6	10,800	43	2,590	3,520	800	1,220	1,050	1,030	411	735
	12	.63	------	8,400	14,400	1,810	2.30	15.0	17,000	43	4,610	6,920	1,260	1,830	1,490	1,300	426	826
Oak, white [6]	70	.59	.72	4,700	8,100	1,200	1.08	11.3	10,900	42	2,940	3,520	850	1,270	1,110	1,070	420	762
	12	.67	------	7,900	13,900	1,620	2.31	13.3	17,400	39	4,350	7,040	1,410	1,890	1,420	1,330	401	756
Sweetgum	81	.44	.53	3,700	6,800	1,150	.81	9.4	10,000	33	2,230	2,840	460	1,070	630	520	330	510
	12	.49	------	8,100	11,900	1,490	2.57	11.3	16,800	32	4,700	5,800	860	1,610	950	690	380	800
Sycamore	83	.46	.54	3,300	6,500	1,060	.60	7.5	8,800	26	2,400	2,920	450	1,000	700	610	330	630
	12	.49	------	6,400	10,000	1,420	1.66	8.5	10,500	26	3,710	5,380	860	1,470	920	770	400	720

Walnut, black	81	.51	.56	5,400	9,500	1,420	1.16	14.6	11,900	37	3,520	4,300	600	1,220	960	900	360	570
	12	.55	------	10,500	14,600	1,680	3.70	10.7	16,400	34	5,780	7,580	1,250	1,370	1,050	1,010	320	690
Yellow-poplar	64	.38	.43	3,400	5,400	1,090	.62	5.4	8,600	18	1,930	2,420	330	740	390	340	220	450
	12	.40	------	6,100	9,200	1,500	1.43	6.8	13,500	20	3,550	5,290	580	1,100	560	450	280	520
SOFTWOODS																		
Baldcypress	91	.42	.48	4,200	6,600	1,180	.91	6.6	8,800	25	3,100	3,580	500	810	440	390	180	300
	12	.46	------	7,200	10,600	1,440	2.15	8.2	10,400	24	4,740	6,360	900	1,000	660	510	170	270
Douglas-fir (Coast Region)	36	.45	.51	4,800	7,600	1,550	.85	6.8	9,800	24	3,410	3,890	510	930	510	480	160	240
	12	.48	------	8,100	11,700	1,920	1.96	8.6	12,700	30	6,450	7,420	910	1,140	760	670	180	300
Douglas-fir (Inland Empire Region)	42	.41	.47	3,600	6,800	1,340	.55	6.9	8,700	22	2,460	3,240	500	870	532	470	190	300
	12	.44	------	7,400	11,300	1,610	1.91	8.6	11,800	27	5,520	6,700	950	1,190	720	630	190	340
Douglas-fir (Rocky Mountain Region)	38	.40	.45	3,600	6,400	1,180	.65	6.8	9,100	20	2,540	3,000	450	880	450	400	160	350
	12	.43	------	6,300	9,600	1,400	1.60	6.4	12,100	26	4,660	6,060	820	1,070	740	630	160	330
Fir, commercial white [7]	108	.36	.41	3,800	5,800	1,120	.75	5.3	8,300	22	2,470	2,810	360	750	390	340	160	265
	12	.38	------	6,300	9,300	1,470	1.55	7.0	11,200	20	3,870	5,380	610	930	710	460	175	250
Hemlock, Eastern	111	.38	.43	3,800	6,400	1,070	.76	6.7	7,900	21	2,600	3,080	440	850	500	400	150	230
	12	.40	------	6,100	8,900	1,200	1.79	6.8	10,700	21	4,020	5,410	800	1,060	810	500	150	------
Hemlock, Western	74	.38	.44	3,400	6,100	1,220	.57	6.8	8,100	22	2,480	2,990	390	810	520	430	190	310
	12	.42	------	6,800	10,100	1,490	1.82	7.5	12,400	26	5,340	6,210	680	1,170	940	580	200	310
Larch, Western	58	.48	.59	4,600	7,500	1,350	1.01	7.1	9,400	24	3,250	3,800	560	920	470	450	160	230
	12	.52	------	7,900	11,900	1,710	2.46	8.0	15,100	32	5,950	7,490	1,080	1,360	1,110	760	160	310
Pine, Eastern white	68	.34	.37	3,100	5,000	1,020	.54	5.2	6,700	17	2,060	2,490	290	660	310	310	140	240
	12	.36	------	6,000	8,800	1,280	1.59	6.7	9,500	19	3,680	4,840	550	860	500	400	160	300
Pine, ponderosa	91	.38	.42	3,100	5,000	970	.59	5.1	6,800	20	2,070	2,400	360	680	300	310	170	290
	12	.40	------	6,300	9,200	1,260	1.85	6.6	9,800	17	4,060	5,270	740	1,160	550	450	220	400
Pine, red	54	.44	.51	3,700	6,400	1,380	.59	5.8	7,500	28	2,410	3,080	360	780	360	340	160	190
	12	.48	------	9,400	12,500	1,800	2.78	10.0	15,900	25	5,330	7,340	830	1,230	670	580	200	490
Pine, southern yellow:																		
Loblolly	81	.47	.54	4,100	7,300	1,410	.68	8.2	8,900	30	2,550	3,490	480	850	420	450	180	260
	12	.51	------	7,800	12,800	1,800	1.92	10.4	12,100	30	4,820	7,080	980	1,370	750	690	270	470
Longleaf	63	.54	.62	5,200	8,700	1,600	.95	8.9	10,100	35	3,430	4,300	590	1,040	550	590	210	330
	12	.58	------	9,300	14,700	1,990	2.44	11.8	15,400	34	6,150	8,440	1,190	1,500	920	870	270	470
Shortleaf	81	.46	.54	3,900	7,300	1,390	.63	8.2	8,600	30	2,500	3,430	440	850	410	440	200	320
	12	.51	------	7,700	12,800	1,760	1.93	11.0	13,600	33	5,090	7,070	1,000	1,310	750	690	270	470
Pine, sugar	137	.35	.38	3,400	5,100	940	.70	5.4	7,400	17	2,330	2,530	350	680	320	310	180	270
	12	.36	------	5,700	8,000	1,200	1.53	5.5	10,700	18	4,140	4,770	590	1,050	530	380	190	350
Pine, Western white	54	.36	.42	3,400	5,200	1,170	.56	5.0	7,600	19	2,430	2,650	290	640	310	310	160	260
	12	.38	------	6,200	9,500	1,510	1.47	8.8	11,900	23	4,480	5,620	540	-------	440	370	160	------
Redcedar, Western	37	.31	.34	3,200	5,100	920	.63	5.0	6,900	17	2,470	2,750	340	710	430	270	140	230
	12	.33	------	5,300	7,700	1,120	1.44	5.8	8,600	17	4,360	5,020	610	860	660	350	130	220
Redwood	112	.38	.42	4,800	7,500	1,180	1.18	7.4	8,900	21	3,700	4,200	520	800	570	410	170	250
	12	.40	------	6,900	10,000	1,340	2.04	6.9	10,200	19	4,560	6,150	860	940	790	480	150	240
Spruce, Eastern [8]	46	.38	.43	3,300	5,600	1,110	.57	6.5	7,000	21	2,120	2,600	290	710	390	340	137	180
	12	.40	------	6,500	10,100	1,440	1.68	8.4	11,400	22	4,160	5,590	590	1,070	630	490	180	355
Spruce, Sitka	42	.37	.42	3,300	5,700	1,230	.53	6.3	8,400	24	2,240	2,670	340	760	430	350	150	250
	12	.40	------	6,700	10,200	1,570	1.62	9.4	11,400	25	4,780	5,610	710	1,150	760	510	210	370
White-cedar, Northern	55	.29	.32	2,600	4,200	640	.60	5.7	5,300	15	1,490	1,990	290	620	320	230	140	240
	12	.31	------	4,900	6,500	800	1.72	4.8	7,100	12	2,630	3,960	380	850	450	320	150	240
White-cedar, Atlantic	35	.31	.35	2,500	4,700	750	.51	5.9	6,000	18	1,660	2,390	300	690	400	290	120	180
	12	.32	------	4,800	6,800	930	1.46	4.1	7,600	13	2,740	4,700	500	800	520	350	130	220
White-cedar, Port Orford	43	.40	.44	4,000	6,200	1,420	.65	7.4	9,200	22	2,770	3,130	350	830	460	400	100	180
	12	.42	------	7,700	11,300	1,730	1.97	9.1	13,500	28	5,890	6,470	760	1,080	730	560	220	400
Yellow-cedar, Alaska	38	.42	.46	3,800	6,400	1,140	.77	9.2	9,100	27	2,500	3,050	430	840	540	440	170	330
	12	.44	------	7,100	11,100	1,420	2.06	10.4	12,200	29	5,210	6,310	770	1,130	790	580	180	360

[1] Test specimens 2 by 2 inches in section. Bending specimens 30 inches long; others shorter depending on kind of test.

[2] Average of Biltmore white ash (*Fraxinus biltmoreana*), blue ash (*F. quadrangulata*), green ash (*F. pennsylvanica lanceolata*), and white ash (*F. americana*).

[3] Black maple (*Acer nigrum*) only.

[4] Silver maple (*Acer saccharinum*) only.

[5] Average of black oak (*Quercus velutina*), laurel oak (*Q. laurifolia*), pin oak (*Q. palustris*), red oak (*Q. borealis*), scarlet oak (*Q. coccinea*), Southern red oak (*Q. rubra*), swamp red oak (*Q. rubra pagodaefolia*), water oak (*Q. nigra*), and willow oak (*Q. phellos*).

[6] Average of bur oak (*Quercus macrocarpa*), chestnut oak (*Q. montana*), post oak (*Q. stellata*), swamp chestnut oak (*Q. prinus*), swamp white oak (*Q. bicolor*), and white oak (*Q. alba*).

[7] Average of lowland white fir (*Abies grandis*) and white fir (*A. concolor*).

[8] Average of black spruce (*Picea mariana*), red spruce (*P. rubra*), and white spruce (*P. glauca*).

into account the variability of the material, the difference between laboratory and service conditions, and the effect of defects, as well as to provide a factor of safety. Such adjustments, except for the effect of defects, have been made by applying a reduction factor to table 5–1 values to provide the basic stresses shown in table 5–2. The reduction factor varies with species, property, and loading condition. For example, the reduction factor for stress in the extreme fiber in bending is about 4. That gives a factor of safety for wood of low quality under long-time loading of about 1⅔, while the average timber has a factor of safety of about 2¼ for long-time loading and about 4 for loading of a few minutes' duration.

The basic stresses of table 5–2 are applicable without modification only to clear material. On the other hand, much material used in house construction contains defects that reduce the strength; for such material, the values of table 5–2 must be reduced to allow for the weakening effect of the defects. Information on which to base such adjustment has been developed by the Forest Products Laboratory (*5–15, 5–17*). Moreover, even clear wood is variable in its strength properties. Because of this variability, design values must be reduced from average properties to take into account the pieces of lower strength that are likely to be used.

The data of table 5–1 may be used in choosing between species for uses in which strength is important. Because of the variability of properties within a species, however, too much dependence must not be placed on small differences in average properties between species. For example, if the moduli of rupture of two species differ by only a few hundred pounds per square inch, it is highly improbable that their bending strength is significantly different, and

TABLE 5–2.—*Basic stresses for clear material* [1]

Species	Extreme fiber in bending	Compression perpendicular to grain [2]	Compression parallel to grain (L/d=10)	Maximum horizontal shear	Modulus of elasticity
SOFTWOODS	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*
Baldcypress	1,733	300	1,466	133	1,200,000
Douglas-fir, Coast Region	2,000	325	1,466	120	1,600,000
Douglas-fir, Coast Region, close-grained	2,133	345	1,565	120	1,600,000
Douglas-fir, Rocky Mountain Region	1,466	275	1,066	113	1,200,000
Douglas-fir, dense, all regions	2,333	380	1,711	140	1,600,000
Fir, commercial white	1,466	300	933	93	1,100,000
Hemlock, Eastern	1,466	300	933	93	1,100,000
Hemlock, Western [3]	1,733	300	1,200	100	1,400,000
Larch, Western	[4] 1,600	325	1,466	133	1,300,000
Pine, Eastern white, Western white,[5] ponderosa, and sugar	1,200	250	1,000	113	1,000,000
Pine, southern yellow [6]	2,000	325	1,466	146	1,600,000
Pine, southern yellow, dense	2,333	380	1,711	171	1,600,000
Redcedar, Western	1,200	200	933	106	1,000,000
Redwood	1,600	250	1,333	93	1,200,000
Redwood, close-grained	1,707	267	1,422	93	1,200,000
Spruce, red, white, and Sitka	1,466	250	1,066	113	1,200,000
White-cedar, Northern and Atlantic	1,000	175	733	93	800,000
White-cedar, Port Orford	1,466	250	1,200	120	1,200,000
Yellow-cedar, Alaska	1,466	250	1,066	120	1,200,000
HARDWOODS					
Ash, black	1,333	300	866	120	1,100,000
Ash, commercial white	1,866	500	1,466	167	1,500,000
Beech, American	2,000	500	1,600	167	1,600,000
Birch, sweet and yellow	2,000	500	1,600	167	1,600,000
Chestnut, American	1,266	300	1,066	120	1,000,000
Elm, American and slippery [7]	1,466	250	1,066	133	1,200,000
Maple, sugar and black [8]	2,000	500	1,600	167	1,600,000
Oak, commercial red and white	1,866	500	1,333	167	1,500,000
Sweetgum [9]	1,466	300	1,066	133	1,200,000

[1] For use only with clear material and as a basis for determining design or working stresses according to the grade of timber and the condition of exposure. They are applicable to material that is continuously dry or continuously wet, except as noted. During the emergency period of World War II, basic stresses (except for modulus of elasticity) were increased 20 percent over the values shown in this table, as a conservation measure. These increased stresses were only applicable in design of buildings.

[2] For material that is continuously wet, take 70 percent of tabulated values.

[3] Also sold as West Coast hemlock.

[4] In setting up basic stresses, consideration has been given to results of tests on small clear specimens and to tests of full-sized timbers of the species when available. That the value for stress in extreme fiber in bending of Western larch should be higher than that listed here is indicated by tests of small clear specimens but is not confirmed by available tests in structural sizes.

[5] Also sold as Idaho white pine.

[6] Also sold as longleaf or shortleaf southern pine.

[7] Sold as white elm or soft elm.

[8] Sold as hard maple.

[9] Sold as red gum.

there is probably little to choose between these two species in this regard. For many uses, species having generally the same characteristics may be grouped so that any species within a group may be used for a particular purpose interchangeably with others in the same group.

5.1. INFLUENCE OF MOISTURE CONTENT ON STRENGTH OF WOOD.—The strength of wood, for most properties, is considerably affected by its moisture content (sec. 3.6). Lowering of the moisture content of green wood to the fiber-saturation point, which for most woods is at approximately 30 percent, does not cause change in dimensions or in strength properties, but reduction in moisture content below the fiber-saturation point results in shrinkage and an increase in most strength properties.

While the strength of a piece of wood may be increased to a relatively high value by drying it to a low moisture content, some of that increase will be lost if, in use, the piece is exposed to atmospheric conditions that increase its moisture content. Although paint and other coatings retard the absorption of moisture, a piece of wood will, in time, come finally to the same moisture content whether coated or uncoated. It is desirable, therefore, to design a structure on the basis of the strength corresponding to the moisture content that will be attained in use (sec. 3.6).

The various strength properties are not equally affected by changes in moisture content. Whereas some properties, such as crushing strength and bending strength, increase greatly with decrease in moisture content, others, such as stiffness, change only moderately, and still others, such as shock resistance, may even show a slight decrease.

The average percentage increase (or decrease) in strength properties resulting from a 1 percent decrease (or increase) in moisture content is:

Property	Percentage change
Static bending:	
Fiber stress at proportional limit	5
Modulus of rupture or cross-breaking strength	4
Modulus of elasticity or stiffness	2
Work to proportional limit	8
Work to maximum load or shock-resisting ability	½
Impact bending:	
Fiber stress at proportional limit	3
Work to proportional limit	4
Height of drop of hammer causing complete failure	½
Compression perpendicular to grain:	
Fiber stress at proportional limit	5½
Compression parallel to grain:	
Fiber stress at proportional limit	5
Maximum crushing strength	6
Hardness:	
End-grain	4
Side-grain	2½
Shearing strength parallel to grain	3
Tension perpendicular to grain	1½

Adjustment of strength for moisture content is seldom if ever made in connection with the use of wood in, or the design of, conventional houses. It is a refinement not justified under present practice in design of houses. The reduction in size of members resulting from the application of engineering principles in the design of prefabricated houses may in the future involve some considerations of the effect of moisture content on strength of wood. Adjustments made using the above data must be recognized as approximate, should not be regarded as having a high precision in individual cases, and are valid only for clear material. They are, however, sufficiently accurate to meet any need that is likely to occur in the near future. More accurate adjustment methods have been devised for use where needed (*5–14*).

The effect of moisture on the strength of plywood depends upon several factors, such as the grain direction, combination of species, relative thickness of plies in each direction, and the like. Approximate corrections for differences in moisture content can be made, however, by assuming the same factors for adjustment of plywood strength values as are shown for solid wood.

These values may, similarly, be used for laminated wood made from veneer, that is, material in which the grain direction of all plies is parallel. For laminated sections made from heavier pieces as, for example, a laminated beam, no data are available to indicate the effect of changes in moisture content on strength properties, but it is probable that the same factors apply.

5.2. INFLUENCE OF DEFECTS ON STRENGTH.

5.20. General.—A system of evaluating the effect of defects on the strength of structural timbers has been developed by the Forest Products Laboratory and is the basis for the grading of commercial structural timber (*5–15*). Lum-

ber graded in accordance with the Forest Products Laboratory principles is available on the market. Very little of it, however, is used in house construction. The commercial stress grades will probably be used even less in prefabricated houses, since the pieces are intended for use in the sizes in which they are graded. When cut into smaller sizes, the values assigned the original pieces are no longer applicable, and the resulting pieces must be regraded before stress values can be assigned them.

The framing for conventional houses and prefabricated houses at present is obtained almost exclusively from Dimension grades. Dimension is not graded in accordance with the principles of strength grading. Unless Dimension is regraded in accordance with structural grading principles, definite working stresses cannot be assigned to it. It is not practical in this publication to discuss in detail the structural grading of lumber for strength.

Information on the defects that do and do not affect strength, and the manner in which they affect strength, is presented and should be of value in aiding builders to obtain better strength results from the dimension grades and other lumber used where strength is important.

The defects and blemishes that occur in wood are described in section 2.3. Those defects that affect strength to the greatest extent and must, therefore, be considered where strength is important, are decay, knots, cross grain, holes, checks, shakes, and splits. Other defects do affect strength but are not important. In small-size members, however, it is desirable to limit their size and location because of their relatively greater percentage effects on members of small size than on members of the size used in framing a conventional house. Thus, a pitch pocket of a given size in a 1- by 2-inch framing member of a panel may materially reduce the strength of the member. The same pitch pocket would be relatively unimportant in a 2- by 8-inch member, because the percentage loss in strength it would cause would be much less, and because it would be less injurious than knots permitted in the grade. There are other defects and blemishes which do not affect the strength or whose effect on strength is so small as to be unimportant even in members of small cross section. They include mineral streaks, indented rings, bird's-eye, bird pecks, red streak in spruce, black streak in Western hemlock and other conifers, and black streak or soot pockets in yellow-poplar.

5.21. Decay.—Decay in any form (sec. 2.39) should be prohibited in all lumber used in housing where strength is an important factor, since no satisfactory method of accurately estimating its extent or its damaging effect on strength has been devised. In addition, stain is frequently prohibited, even though, in itself, it has little effect on strength, since its presence indicates that the material has been subjected to conditions conducive to decay, and because the presence of stain may serve to mask, to some extent, the colorations indicating decay.

5.22. Knots.—The weakening effect of knots results from two factors. The fibers of a knot are essentially at right angles to those of the piece of lumber, so that the strength of the knot in the main fiber direction is that perpendicular to grain, which is low compared with that parallel to grain. In addition, the fibers of the main piece surrounding the knot are distorted so that an area of localized cross grain surrounds the knot. In general, encased knots or knotholes from which encased knots have fallen are no more injurious to bending strength than intergrown knots. Grain distortion increases at a greater rate than is represented by the increase in knot size, so that the injurious effects of knots increase more rapidly than does knot diameter. Knots or knotholes are generally more damaging to strength than holes from birds, insects, or tools, since the latter are not generally associated with any distortion of the surrounding grain.

Knots are more injurious to bending and tensile strength than to compressive strength, and have little effect on shear strength or stiffness. Thus, in a long column, where load-carrying capacity depends primarily upon stiffness, and in joists, where deflection is important, knots have little effect. In a beam subjected to bending forces, it is possible to estimate with fair accuracy the effect of knots by their size and position. They are most injurious when they are on or near the bottom face of the beam and within the central portion of the length.

How knots are measured is shown in figure 5–1. In joist and plank (fig. 5–1, *A*), the size of a knot on a narrow face (knots that extend into a wide face are not measured on the narrow face) is taken as its width between lines parallel to the edges of the piece; on a wide face, the

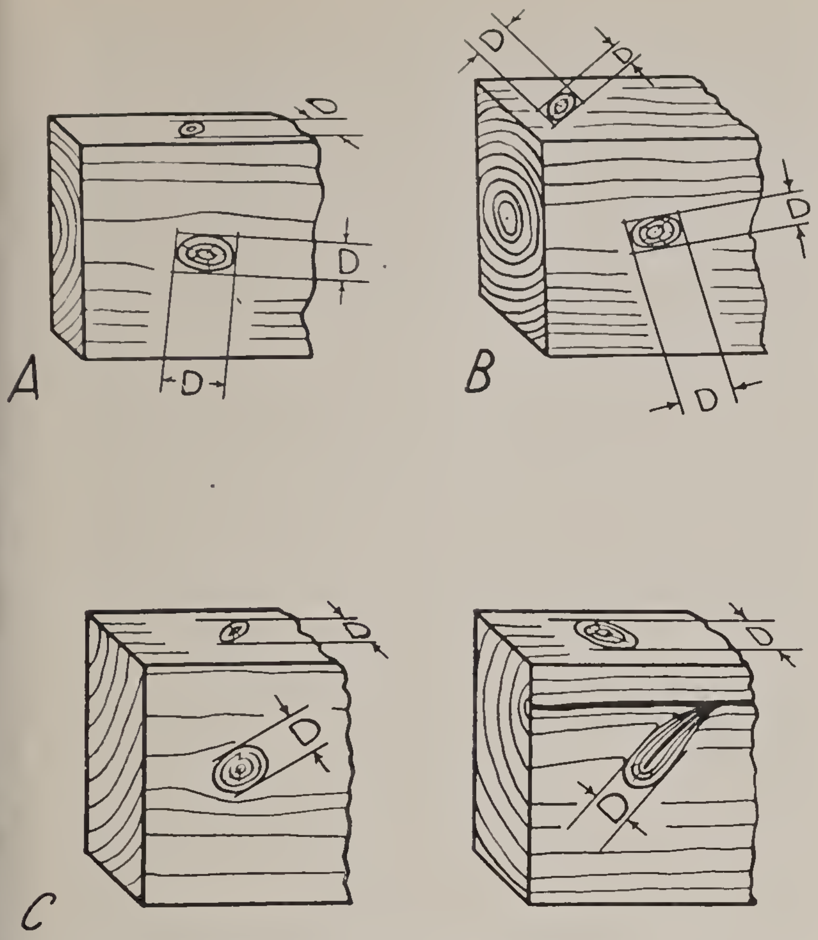


FIGURE 5–1.—Measurement of knots: *A*, in joist and plank; *B*, in posts and timbers; *C*, in beams and stringers.

size is taken as one-half the sum of its largest and smallest diameters and the size of a spike knot is taken as one-half the sum of its length and greatest width. In posts and timbers (fig. 5–1, *B*), the size of knot on any face is taken as one-half the sum of its largest and smallest diameter and the size of a spike knot is taken as one-half the sum of its length and greatest width. In beams and stringers (fig. 5–1, *C*), the size of knot on a narrow face is taken as its width between lines enclosing the knot and parallel to the edges of the piece (except that when a knot on a narrow face extends into the adjacent one-fourth of the width of a wide face its least dimension is taken as its size); on a wide face, the size of knot is taken at its smallest diameter.

The injurious effect of knots decreases as their distance from the center of the span increases (fig. 5–2), so that a knot near the end of the beam has little effect on strength. Also the injurious effect decreases as the position of the knot changes from near the bottom face to the center line of the vertical face.

Knots in posts reduce compressive strength about in proportion to the percentage of the cross section which they occupy, regardless of their position in the post. The average diameter of a knot is a good measure of that effect (fig. 5–1, *B*). Thus, a 1-inch knot anywhere in a 4-inch face will reduce the strength 25 percent. Unless more than one knot is in the same cross section, the effect is not cumulative. Material to be acceptable for posts, therefore, should have the knots so dispersed that no two knots of maximum size will occur in any 6 inches of length.

The effect of knots on members subjected to tension stress only is more pronounced and more difficult to evaluate than in compression members. Knots in tension members should therefore be rigidly limited—that is, in members such as lower chords of trusses and tension diagonals. No rules for limiting defects in tension members have been developed, but the limitations for the center half of beams described in reference (*5–15*) are applicable, with the added limitation that the sum of the diameters of all knots in any 6 inches of length shall

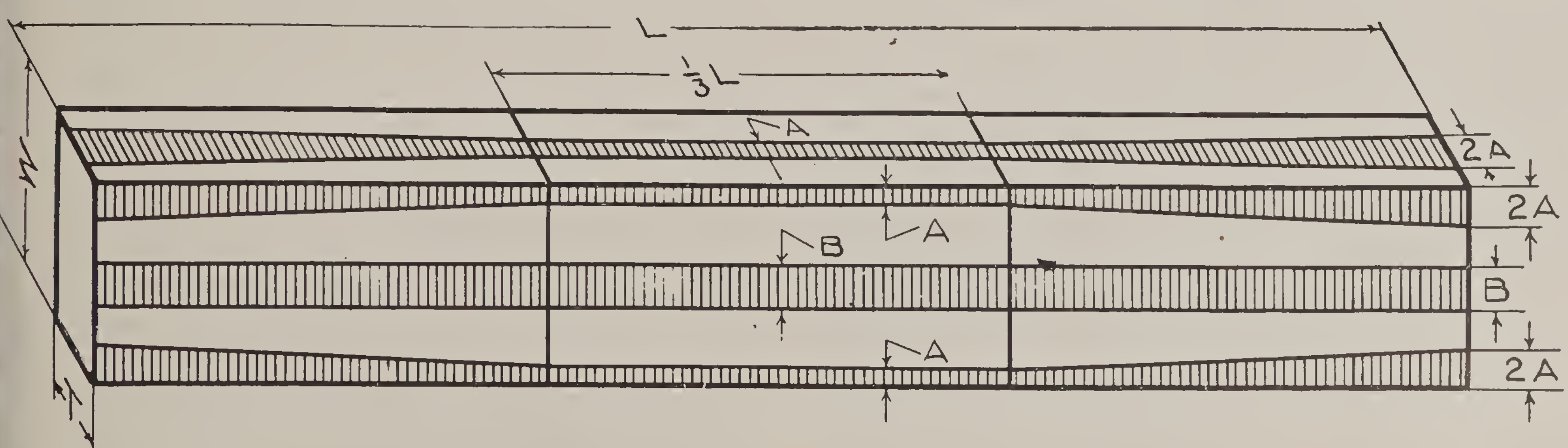


FIGURE 5–2.—Maximum size of knots permitted in various parts of beams and stringers and joist and plank: *A*, maximum size on narrow faces or edge of wide faces, within middle third of length, with a gradual increase to *2A* at ends of piece (*2A* may not exceed *B* for beams and stringers); *B*, maximum size at center line of wide face; *L*, length; *W*, width; *T*, thickness.

not exceed twice the size of the maximum knot permitted.

Cluster knots should be prohibited where strength is of importance, since neither the size of the knots nor the size of the cluster is a good measure of the amount of grain distortion they cause, and consequently neither adequately indicates the effect of the cluster on strength.

5.23. Cross Grain.—The strength of wood differs greatly in the prinicpal directions with respect to the grain. Strength parallel to grain may be 10 or more times greater than that perpendicular to grain. Any deviation of the fiber direction from a direction parallel to the axis of the piece constitutes cross grain (sec. 2.32). In a member in which the fibers all run parallel to the axis of the piece, the principal stress acts in the fiber (strong) direction. In a piece containing cross grain, however, one component of the stress acts in the across-the-grain (weak) direction, while the other component acts in the along-the-grain (strong) direction. Thus the net effect with respect to stress acting parallel to the axis of the piece is a reduction in strength.

TABLE 5–3.—*Average percentage deficiency* [1] *in strength properties of cross-grained material at various slopes with respect to straight-grained material*

Slope of grain	Static bending			Impact bending, maximum drop	Maximum crushing strength
	Modulus of rupture	Modulus of elasticity	Work to maximum load		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1:25	4	3	13	5	0
1:20	7	4	21	10	0
1:15	11	6	31	19	0
1:10	19	11	48	38	1
1:5	45	33	68	64	7

[1] Based on tests of small clear specimens of white ash, Douglas-fir, and Sitka spruce.

Average reductions in strength with increasingly steep cross grain are shown in table 5–3. These data are based on tests of small clear specimens free of checks. In larger sizes, checks are usually present, and the effect is greater. Compressive strength is not appreciably affected until a slope of 1 in 10 is reached, while bending strength is more quickly affected and shows an appreciable reduction at a slope of 1 in 20. Stiffness in bending is somewhat less affected than is bending strength, showing an appreciable reduction at a slope of 1 in 15, while shock resistance shows a deficiency at a slope as flat as 1 in 25 and decreases rapidly as the slope becomes steeper.

5.24. Shakes and Checks.—Shakes and checks (sec. 2.34) reduce the strength of beams by reducing the area available for resistance to horizontal shear and by causing stress concentrations at the base of the checks or shakes. The effect of stress concentration is taken into account in deriving basic working stresses (table 5–2), while the effect of reducing shear area is taken into account by limiting the size of the defects in grading rules. They have a smaller effect on the strength of posts than on the strength of beams and, when vertical, do not greatly affect the shearing strength of beams, since the horizontal projection is relatively small. The effect of shakes and checks is approximately proportional to the amount by which they reduce the shear-resisting area. In beams and stringers or joists and planks the size of a shake is measured by the distance between lines enclosing the shake and parallel to the wide face of the piece. In posts and timbers a shake is measured by the distance between the maximum spaced pair of lines exactly enclosing the shake and parallel to opposite faces (fig. 5–3).

5.25. Holes.—Holes in wood other than knotholes may be caused by worms, insects, birds, or careless use of tools. The effect of holes from

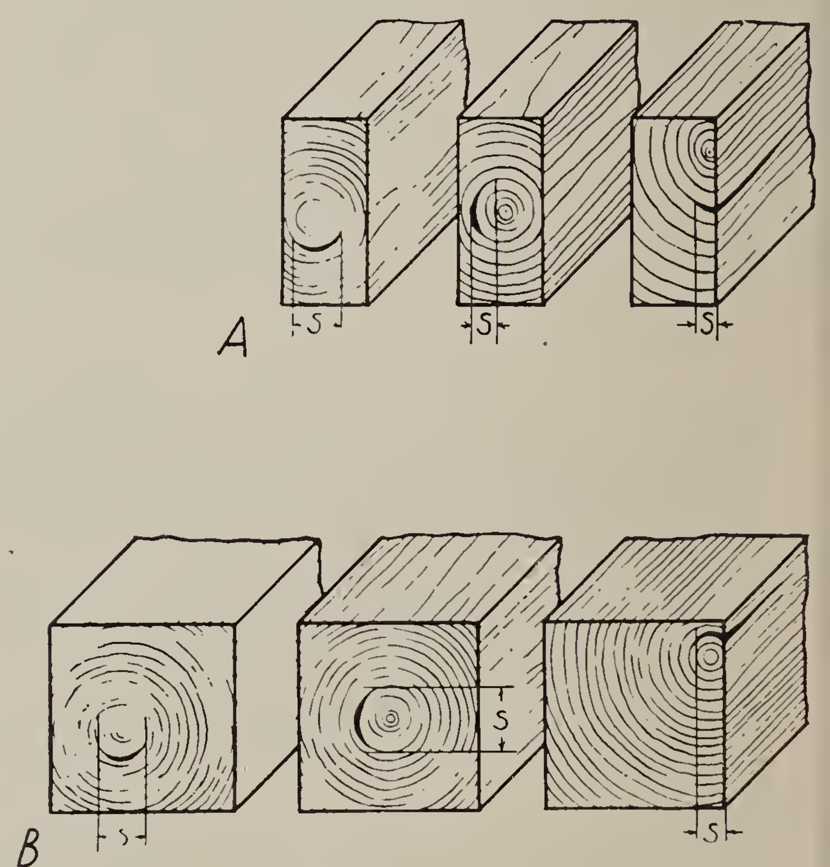


FIGURE 5–3.—Measurement of shakes: *A*, in beams and stringers; *B*, in posts and timbers.

such causes is less than that of knotholes because there is usually no distortion of grain around them. Holes other than knotholes seldom affect strength of timbers as much as other permitted defects. In members of small cross section, holes from all causes may become important because of the fibers that have been cut if they occupy a sufficiently large proportion of the cross section.

5.26. Compression Wood.—The bending and tensile strength, stiffness, and shock resistance of compression wood (sec. 2.33) are low and its shrinkage lengthwise of the piece is high. From the standpoint of low strength, and that of the troubles to be expected from shrinkage, compression wood, especially in the pronounced form, should be excluded from material going into houses. Fortunately, compression wood is limited to softwood species and is found in only a small percentage of lumber. In addition, its tendency to warp badly will probably cause it to be culled, if any seasoning takes place, before it reaches the factory.

5.27. Compression Failures.—Compression failures should not be confused with compression wood (sec. 5.26). Material containing compression failures (sec. 2.35) has only a portion of its strength left, since some of the fibers have already been broken. Thus, when compression failures are present on the tension side of a beam, they usually cause an abrupt and complete fracture across the grain, frequently under relatively low loads. While failures that are not readily detectable with the unaided eye are not likely to cause serious loss in strength of large timbers, even those that are almost invisible will seriously reduce the strength and shock resistance of small members. Any material containing compression failures should be rejected if it is to be used in load-carrying members. Only a small percentage of lumber contains serious compression failures.

5.28. Minor Defects.—Pitch pockets, bark pockets, pitch streaks, pitch flecks, and burls (secs. 2.36, 2.37) generally do not have an important effect on strength, except when they are exceptionally large. In structural timbers, only the larger sizes are of importance in reducing strength, although in smaller members their effect may become important. The effect of pitch and bark pockets on strength may be judged, as are holes, by the percentage of the cross section that they replace. Burls weaken the member by distorting the grain and should be treated much as are knots with respect to the member under stress. In general, burls will have an appreciable effect only on small members.

5.3. OTHER FACTORS AFFECTING STRENGTH OF WOOD.

5.30. General.—The strength of wood is affected by many factors. Perhaps the factor most readily recognized is that of defects, such as knots, shakes, and cross grain (sec. 5.2). The strength of clear wood free from defects is also affected, however, by such factors as moisture content (sec. 5.1), density, and rate of growth. In addition, while it is popularly believed that certain other factors have an influence on strength, reliable data have indicated many of these beliefs to be false. The influence of certain of these factors will be discussed briefly in this section.

5.31. Effect of Density on Strength.—The density or specific gravity (sec. 3.5) of a piece of wood is an excellent index of the amount of wood substance contained in the piece, and hence of the strength of the piece. In general, a species of high density is higher in most strength properties than a species of lower density. Differences in the structural arrangement of the fibers or in the amount of resins, gums, or other extractives (which add to the weight but do not contribute so much to the strength as would a like amount of wood substance) may cause two species of the same average specific gravity to exhibit different strength characteristics. Likewise, some species of wood are equal in some respects to others of higher density. Departure of a species from the general relationship often indicates some exceptional characteristic which makes this species particularly desirable for certain use requirements.

Density affords a still better index of strength within a species than between species. The heaviest pieces of any species are generally 2 to 3 times as high in density as the lightest, and are correspondingly stronger. This characteristic is recognized in the stress grades by allowing higher working stresses for dense material of certain softwood species.

In structural grades, pieces of extremely low strength are generally excluded by not admitting to the grade pieces of exceptionally light

weight. Increased working stresses are permitted in two species, southern yellow pine and Douglas-fir, where the pieces meet a density requirement measured in terms of a minimum percentage of summerwood combined with a normal growth rate (table 5–2). This method can be used in the factory to select high-quality material of those species. The better facilities available in the factory may make it possible to use more efficient methods of selecting high-strength material of any species on the basis of specific gravity. At present even the rough method used in determining the density of Douglas-fir and southern yellow pine is seldom applied to those species in factories.

5.32. Effect of Rate of Growth on Strength.—Rate of growth as indicated by the width of the annual rings (or by the number of rings per inch) is of some assistance in appraising the physical and mechanical properties of wood, but it cannot be regarded as an efficient criterion. In any species, wood of excellent mechanical properties may vary considerably in rate of growth, but such material will quite consistently be of high density.

Among the ring-porous hardwoods, such as oak, ash, elm, and hickory, fast growth (few rings per inch) is generally indicative of good strength properties, although slow growth does not necessarily indicate weak material. An exception is found in the rapid-growth material from swelled butts of swamp-grown trees. Among the diffuse-porous hardwoods, such as beech, birch, maple, and yellow-poplar, no consistent relation between rate of growth and strength has been found.

While softwood species show a wide range of strength and density at each rate of growth, usually the strongest material is associated with a normal growth rate. Exceedingly rapid or exceptionally slow growth is likely to be attended by low density and low strength. Limitations on the range in the number of rings per inch in structural grades for some softwood species are accompanied by increased allowable working stresses.

5.33. Effect of Rate and Method of Loading on Strength.—The duration of stress or the time during which a load or force is applied to a beam or other wood member, as well as the rate at which the load is applied, have an important bearing on the adaptation of test results to the design of structures or structural members. For example, in impact-bending tests where the load is suddenly applied, a stick will resist more than double the load that will produce failure in a test in which the load is applied in a period of perhaps 3 to 5 minutes. On the other hand, beams under continuous loading for years will fail at loads one-half to three-fourths as great as would produce failure in a standard laboratory bending test. In the determination of basic working stresses (table 5–2), average test results are reduced by a factor to take into account the effect of long-time loading.

5.34. Strength of Heartwood and Sapwood.—Tests have indicated that there is, in general, no intrinsic difference in strength between heartwood and sapwood (sec. 2.13), and that many popularly supposed differences do not exist. Sometimes, however, the nature and amount of extractives may have an effect on strength, depending upon the species, the moisture content, and the property considered. Maximum crushing strength in compression parallel to grain shows the greatest increase as the result of infiltration of extractives accompanying the change of sapwood into heartwood, with shock resistance the least and modulus of rupture intermediate.

5.35. Effect of Time or Season of Cutting on Strength.—It is popularly supposed that the time or season of cutting affects the strength of wood, but available data do not support this supposition. The method of handling after cutting and the loss due to seasoning defects and attack by insects and fungi in summer cutting are of greater importance.

5.36. Effect of Live and Dead Trees on Strength.—Sound wood from trees killed by insects, storms, or fire is, unless unduly checked, as good for structural purposes as that from trees alive when felled. Dead trees not deteriorated from any cause can, therefore, furnish suitable material. Since dead trees on the stump or on the forest floor are subject to attack by decay organisms, and since even decay that is not readily detected may result in loss in strength, timber from dead trees needs careful inspection. Specifications requiring timber only from live trees are difficult of enforcement unless inspection is made in the forest, since wood from dead trees, unless weathering, seasoning, decay, insect attack, or similar change has occurred, cannot be

distinguished from the wood of trees alive when felled.

5.37. Strength of Air-dried and Kiln-dried Wood.—Claims have been made that air-dried wood is stronger than kiln-dried wood and the reverse. Comparative tests have shown, however, that good air drying and good kiln drying have the same effect on strength. It is important, however, to note that severe kiln conditions may injure the strength of a piece of wood without producing any visible difference in appearance. Good kiln drying requires the proper application of kiln conditions appropriate to the species, grade, and thickness being dried (sec. 9.1).

5.4. STRENGTH OF PLYWOOD.—Plywood (sec. 3.2) has more nearly equal strength properties along the length and width of a panel than does solid wood. This characteristic is obtained by alternating the direction of grain of successive plies. Considering the strength along the width of a panel in comparison with that of a solid piece, a portion of the across-the-grain (weak) material has been replaced by along-the-grain (strong) material, giving a net gain in strength in this direction. While it is evident that the strength along the width has been increased by replacing weak material with strong, it is evident also that the strength along the length has been decreased by the substitution of weak material for strong. Thus the common belief that plywood is stronger than wood is, in general, wrong, although in certain properties plywood's strength is higher than that of solid wood. As a result of its construction, plywood shrinks less and splits much less readily than solid wood.

The strength of plywood in tension, compression, bending, and other properties is dependent not only on the strength of the wood and the size of the member but also on the number of plies, their relative thicknesses, the grain direction of adjacent plies (generally 90°), and the direction of load with respect to the face grain. In addition, veneers of different species are sometimes combined. The determination of the strength of a particular piece of plywood is, therefore, complicated, and tables showing the various strength properties of all possible combinations of species and ply thickness are impractical. It is beyond the scope of this manual to present the fundamental methods available for computing the strength properties of plywood (*5–1*). In the design of houses, approximate methods will suffice. Approximate methods for computing various strength properties of plywood are given in table 5–4. These methods, used in conjunction with the basic stresses of table 5–2, will probably suffice for the design of many members involving plywood, including stressed-cover panels (sec. 14.1111).

In using the methods of table 5–4, it must be remembered that the basic stresses of table 5–2 are for clear wood without defects. An appropriate reduction factor must be used depending upon the grade of plywood used. For example, when the defects present are estimated to reduce the strength one-fourth, multiply the basic stresses by three-fourths. No accepted method of estimating the damaging effects of defects in plywood has yet been established. Estimated strength ratios have been established (*5–2*) for the commercial Douglas-fir grades as follows (sec. 4.1): Good 2 Sides, 100 percent; Good 1 Side, 95 percent; Sound 2 Sides, 87½ percent; Wallboard or Sound 1 Side, 80 percent; Sheathing, 75 percent.

Since the basic stresses of table 5–2 are based on green material, an increase may be allowed for plywood used under continuously dry conditions. Increases may be computed in accordance with section 5.1.

5.5. STRENGTH OF LAMINATED WOOD.—The strength of a member made of laminated wood is affected by more factors than is that of a solid member. It is dependent not only on the species, quality, and grade of lumber, as is a solid member, but also on the method of joining the laminations and on the quality of workmanship. In a sense, it is also dependent on the kind of glue used, since some glues do not retain their strength under adverse exposure conditions and, if the glue joint loses strength, the strength of the laminated member will be adversely affected.

The efficiency of the fastenings joining the laminations is of considerable importance in determining the strength of laminated members, particularly in the case of horizontally laminated members, that is, members so arranged that the wide dimensions of the laminations are perpendicular to the direction of the applied load. In such a case, the fastenings must provide sufficient shear resistance to prevent slipping of one lamination on the other. Bolted,

nailed, or screwed horizontally laminated beams are not so strong as comparable solid members, because the resistance to slipping provided by these fastenings is not so great as that provided in a solid beam. In vertically laminated beams, the fastenings must be adequate to cause all parts to deflect together and thus to contribute proportionally to the load-carrying capacity, as well as to fasten the several parts together so that no one part becomes elastically unstable.

In general, the strength of mechanically fastened laminated members lies somewhere between that of a comparable solid member and the sum of the individual laminations acting separately. Within these limits, the strength of mechanically fastened laminated members depends upon the position of the laminations with respect to the load and upon the number, size, and efficiency of the fastenings. Glued laminated members, on the other hand, are as strong as the wood and are permanent. Glues are available that will produce such joints (sec. 11.1).

Even with glued joints, assuming that they are permanent and as strong as the wood, the strength of laminated members will vary with the manner in which the available material is selected and placed. For example, it has been found that the bending strength and stiffness of laminated beams containing knots are controlled by a factor which is dependent upon a

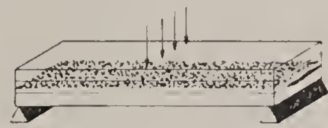
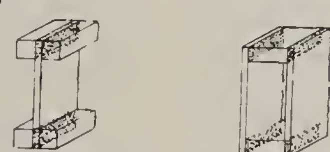
TABLE 5–4.—*Design method and allowable stresses for plywood* [1]

Property	Direction of stress with respect to direction of face grain	Area to be considered	Unit stress to be used
Tension	Parallel or perpendicular	Parallel plies [2] only	Unit stress for extreme fiber in bending
	± 45°	Full cross-sectional area	One-sixth unit stress for extreme fiber in bending
Compression	Parallel or perpendicular	Parallel plies [2] only	Unit stress in compression parallel to grain
	± 45°	Full cross-sectional area	One-third unit stress in compression parallel to grain
Bearing at right angles to plane of plywood		Loaded area	Unit stress in compression perpendicular to grain
Load in bending	Parallel or perpendicular	Bending moment M = KSI/c where S = unit stress for extreme fiber in bending; I = moment of inertia computed on basis of parallel plies only; c = distance from neutral axis to outer fiber of outermost ply having its grain in the direction of the span; K = 1.50 for three-ply plywood having the grain of the outer plies perpendicular to the span; K = 0.85 for all other plywood	Unit stress for extreme fiber in bending
Deflection in bending	Parallel or perpendicular	Deflection may be calculated by the usual formulas, taking as the moment of inertia that of the parallel plies plus one-twentieth that of the perpendicular plies. (When face plies are parallel, the calculation may be simplified, with but little error, by taking the moment of inertia as that of the parallel plies only.)	Unit value for modulus of elasticity
Deformation in tension or compression	Parallel or perpendicular	Parallel plies [2] only	Unit value for modulus of elasticity
Shear through thickness	Parallel or perpendicular	Full cross-sectional area	Double unit stress in horizontal shear
	± 45°	Full cross-sectional area	Four times unit stress in horizontal shear

[1] The suggested simplified methods of calculation apply reasonably well with usual plywood types under ordinary conditions of service. It is recognized, however, that they are not entirely valid for all types of plywood and plywood constructions, or for all spans and span-depth ratios. Also the methods given are not applicable to structures so proportioned that the plywood is in the buckling range, in which event the results will be too high.

[2] By "parallel plies" is meant those plies whose grain direction is parallel to the direction of principal stress.

TABLE 5-4.—*Design method and allowable stresses for plywood* [1]—Continued

Property	Direction of stress with respect to direction of face grain	Area to be considered	Unit stress to be used
Shear in plane of plies	Parallel or perpendicular	Full shear area. 1. Plywood beams. Horizontal shear: 	1. Three-fourths unit stress in horizontal shear
		Area of contact between plywood and flange or framing member. 2. I- or box-beams with plywood webs. Shear between plies of web or between web and flange: 	2. Three-eighths unit stress in horizontal shear
		3. Panels having plywood covers stressed in compression or tension, or both. Shear between plies or between cover and framing members when depth of member exceeds twice its width and end headers are used or when depth is not more than twice the width and no headers are used. A. Interior framing members: 	3. A. Three-fourths unit stress in horizontal shear
		B. Framing members at edge of panel: 	B. Three-eighths unit stress in horizontal shear
	± 45°	Area of contact between plywood and flange or framing member. 1. I- or box-beams with plywood webs. Shear between plies of web or between web and flange. 	1. One-half unit stress in horizontal shear
		2. Panels having plywood covers stressed in compression, or tension, or both. Shear between plies or between cover and framing members when depth of member exceeds twice its width and end headers are used or when depth is not more than twice the width and no headers are used. A. Interior framing members: 	2. A. Unit stress in horizontal shear
		B. Framing members at edge of panel: 	B. One-half unit stress in horizontal shear

ratio Ik/Ig, where Ik is the moment of inertia about the gravity axis of the cross section of the areas of the knots and Ig is the moment of inertia of the full cross section of the beam about the gravity axis. Obviously, the moment of inertia of a knot of a given size will be much smaller if it is located near the center of the depth of a beam than if it is located near the top or bottom. Greater strength will be attained, therefore, if the clearer material is placed in the outer portions of the depth of a beam and the knottier material in the central portions of the depth. In compression members it has been found that knots within a limited portion of the length must be considered as being at a single cross section, so that knots, for highest strength, should be dispersed as much as possible. The effect of knots on compression strength is controlled by a factor which is dependent upon the ratio K/b where K is the size of knot and b is the width of the lamination.

Butt joints are, of course, a source of weakness both in tension and compression. They can transmit no tension stresses and are incapable of transmitting compressive stress without excessive deformation unless they are well fitted. Well-made scarf joints, on the other hand, may have a high percentage of the strength of the uncut board if they have sufficiently flat slope. Very steep scarf joints have a low efficiency in tension.

Butt joints should never be used in tension members or in the tension half of beams. They may be used in the compression half of beams, but in computing the moments of inertia of such beams, all laminations having joints within a portion of the length of the beam less than about 30 times the thickness of the laminations must be considered as being completely ineffective. Scarf joints as steep as 1 in 5 and spaced as close as 10 times the thickness of a lamination may be used on the compression side of beams without modification of the moment of inertia.

When used on the tension side of beams, scarf joints should not be spaced closer together, center to center, than about 24 times the thickness of a lamination and should be placed in such locations that the stress will be no greater than the strength, which is determined by their efficiency.

Where butt joints are used in compression members, all laminations having butt joints within a portion of the length equal to 30 times the thickness of a lamination must be disregarded in computing the effective cross section. Scarf joints as steep as 1 in 5 and spaced as closely as 10 times the lamination thickness may, however, be used without reduction in effective cross section.

Stresses are induced in bending laminations to curved form. Allowable bending stresses in a curved member, therefore, must be reduced by a factor that is dependent upon the ratio of the radius of curvature to the lamination thickness. Joints in curved members should be avoided, so far as possible, and defects which would prevent bending of laminations to a smooth curve without localized irregularities should be prohibited.

The shear strength of a member composed of laminations seasoned in thicknesses of 2 inches or less may be expected to be somewhat higher than that of large solid members because of the lesser effect of checking. Shear strength appears not to be affected by the presence of knots or end joints in the laminations.

Somewhat higher stresses may be assigned to laminated members made from dry material and used under dry conditions than would be assigned to large one-piece members.

5.6. STRENGTH OF MODIFIED WOODS AND PAPER-BASE LAMINATES.

5.60. General.—The chief advantage of most forms of modified wood as compared with normal wood or plywood is their greatly improved moisture resistance and dimensional stability, and significant increase in hardness and strength in compression.

The strength properties are affected principally by such factors as nature or degree of treatment, degree of compression, grain direction of adjacent plies in the case of laminates, and, to a lesser extent, species. Modified woods may vary in specific gravity (density) from slightly greater than normal wood to 1.4 depending on species, the amount of impregnating resin or other chemical used, and the degree to which it is compressed. On the basis of equal weight, normal wood is in general superior to modified wood in flexural strength and stiffness, as good or better in tension parallel to grain, but inferior in compressive strength and in stiffness properties across the grain (*5–3*). All forms of modified wood involving resin treat-

ment are less tough than the original wood. The embrittlement increases with an increase in the amount of resin used and with the improvement in distribution of resin through the structure. Consequently, the use of modified wood may be justified only when dimensional stability, decay, termite, marine borer, and chemical resistance, or other related properties are sought, or when increased strength is of importance, irrespective of an increase in weight.

5.61. Impreg.—Only a few of the strength properties of wood are significantly increased by resin impregnation (*5–11*), which produces impreg (sec. 3.43). Hardness and compressive strength are increased substantially. The hardness is approximately that which would be expected from the increased specific gravity. Resin treatment improves the stiffness of all species, notably across the grain. In laminates made from rotary-cut veneer, shear in the plane of the plies is improved. Tensile, toughness, and impact strengths are significantly decreased by resin impregnation.

5.62. Compreg.—Resin impregnation plus compression produces a general increase in all properties of normal wood except toughness and impact strength (*5–12*). Compreg (sec. 3.43) is superior to impreg in toughness but is not so tough as the original wood. The compressive properties of all species examined are greatly improved, whereas the tensile and flexural properties are increased about in proportion to the degree of compression of the wood. The notable superiority of compreg over normal wood in compressive properties is chiefly due to the high degree to which wood is compressed. The improved bonding of the structural units within the cell wall to each other and the increased transverse cohesion between fibers also contribute to the compressive strength. Impregnated wood is more easily compressed than untreated wood when stabilizing resins are used, due to the plasticizing action of the resin-forming chemicals prior to setting of the resin.

5.63. Staypak.—Compression of wood to a high degree of densification at elevated temperature without resin impregnation produces a general increase in all strength properties (*5–10*) about in proportion to the increase in density, with the exception of shear and toughness. Untreated highly compressed wood can be made so that it does not lose its compression under swelling conditions (staypak). Staypak (sec. 3.43) is comparable to normal wood in toughness and tangential shear. It is, however, not so moisture resistant as resin-treated wood, but in other respects it has the same general characteristics as resin-treated compressed wood, plus the advantage of improved toughness, twice the impact strength, and somewhat improved tensile and flexural properties. Staypak is inferior to compreg only in compressive strength, tangential shear, and in stiffness properties across the grain.

5.64. Acetylated Wood.—The most effective means of stabilizing the dimensions of wood that has been found up to the present time is to acetylate the wood (sec. 3.43). When this is done with a non-acid catalyst in the vapor phase, none of the strength properties appear to be reduced. The specific gravity of the wood is increased by from 6 to 12 percent, the heavier woods showing the smaller increase. The toughness in some cases is increased by as much as 20 percent. Compression perpendicular to the grain and the modulus of rupture are in general increased significantly more than the specific gravity.

5.65. Staybwood.—Dry wood that has been heated to high temperatures for periods of time which just avoid charring has improved dimensional stability and decay resistance. The strength properties are considerably decreased by this treatment. When the heating is done in the absence of air under a molten metal, oil, or salt to produce staybwood (sec. 3.43), the loss in strength is at a minimum. Preliminary tests indicate that losses in flexural strength and hardness up to about 20 percent may occur when heating is carried to the point of reducing the swelling and shrinking by 40 percent. Under these conditions, the toughness of the wood is about one-half of normal. Possible uses will be governed largely by the allowable loss in toughness.

5.66. Paper-base Laminates (Papreg).—The strength properties of paper-base laminates (sec. 3.43) are influenced by such variables as wood species, pulping processes, papermaking procedures, type and amount of resin, and molding conditions. Superior strength and stiffness are achieved through the use of thin, dense papers produced from high-strength softwood pulps and formed in such a manner as to have

a high percentage of fibers alined in the machine direction of the sheet. Papreg is a high-strength laminate made from such paper impregnated with from 25 to 35 percent of phenolic resin and molded under heat and pressure to a specific gravity of about 1.4. Similar high-strength paper-base laminates are available commercially under a number of trade names.

Parallel-laminated papreg, having the machine direction (grain) of adjacent sheets parallel to each other, has almost twice as great tensile and bending strength parallel to the grain direction (lengthwise) as crosswise of the laminate. These strength properties can be equalized along the length and width of the laminate by alternating the direction of the grain of successive sheets (0° and 90°) to form a cross-laminated material. The tensile and bending strength of cross-laminated material is intermediate between those for the two principal directions of the parallel-laminated type. Compressive properties edgewise are about the same regardless of type, because resin is the major factor. Papreg has twice the compressive strength in the molding pressure direction (flatwise) that it has parallel to the laminations (edgewise). Papreg is lower in stiffness, compression parallel to grain, and impact strength than compreg, but is superior in shear, bending, and tensile strengths.

While papreg is superior to fabric-base laminates in most strength properties under impact loading, it is only about one-half as strong. Papreg has good resistance to abrasion and fire and reasonable moisture resistance. Long exposure to high humidity results in some loss in strength, as well as an increase in thickness and moisture content.

Actual data on strength and other properties of papreg as determined by means of standard tests under normal conditions of temperature and humidity are available (*5–3*). Some data on the effect of environmental conditions on the mechanical properties of papreg, such as temperature, moisture, freezing and thawing, accelerated weathering, and natural aging and weathering, are also available (*5–9*, *5–4*).

5.7. STRENGTH OF SANDWICH CONSTRUCTIONS.—The recent development of sandwich-type constructions as housing materials (sec. 3.44) has not permitted ample time to explore all of the strength and other properties of these materials. Enough has been learned, however, to indicate that, in general, the properties of these constructions make them highly promising from the standpoint of strength. Research has demonstrated that sandwich constructions can be designed for adequate strength, stiffness, and light weight. While these properties vary somewhat depending upon the materials used in the construction, sandwiches well suited to housing can be made of inexpensive materials, such as paper or fiber cores and plywood or light metal faces.

From the strength standpoint, the sandwich behaves in the same structural fashion as an I beam. The strong, stiff faces are placed far enough away from the center of the section so that adequate strength and stiffness are developed for the design loads. The core serves, from the standpoint of strength, primarily to separate the faces but must have sufficient strength to carry the shear stresses developed by loads acting upon the faces. These shear stresses are usually low, because the loads acting upon the faces are not excessive. The design problem in housing, thus, is simply to place enough strong material in the faces to carry the direct loads (for example, load from roof to wall) and then to space the facings with a core thick enough to provide the entire sandwich with sufficient stiffness.

While the ratio of core thickness to stiffness varies somewhat with the kind of material used, in general stiffness increases as the square of the thickness. To develop the full stiffness of which the materials are capable, good gluing is essential. Poor gluing (sec. 11.4) will materially reduce stiffness as well as strength. Tests have demonstrated that sandwich constructions usually fail in shear at a glue line.

5.8. STRENGTH OF FIBERBOARD.—Fiberboards commonly used in house construction are made from a variety of materials (sec. 3.42). Most such boards are designed to serve as insulation and for this purpose are of relatively low density, usually in the range of about 15 to 26 pounds per cubic foot. Because of the range in materials and density, it is difficult to generalize on the strength properties of fiberboard.

Test data (*5–13*) on fiberboards covering a fairly wide range of densities indicate that bending strength and nail-holding power increase with increasing density, but that for any

given density there is a considerable range in strength. Despite this variability, it is clear that, where high strength is needed, the denser boards should be used.

Accelerated aging and outdoor weathering of some types of boards (*5–6, 5–7*) generally reduced bending strength or nail-holding power 15 to 25 percent. Some of the laminated boards showed losses in strength in the accelerated aging tests because of delamination when heated to about 150° F. Outdoor weathering did not cause similar delamination. General observation, however, has indicated that some types of board laminated from paper delaminate readily on exposure to free water and lose most, if not all, their strength. Since exposure to free water may occur not only during shipment and storage on the site but also after assembly as a

TABLE 5–5.—*Properties of fiber building boards and effect of accelerated aging* [1]

Thickness	Density	Flexure properties[3]: Breaking load: Across long direction: Before aging	Breaking load: Across long direction: After aging	Breaking load: Across short direction: Before aging	Breaking load: Across short direction: After aging	Deflection at rupture: Across long direction: Before aging	Deflection at rupture: Across long direction: After aging	Deflection at rupture: Across short direction: Before aging	Deflection at rupture: Across short direction: After aging	Nail-holding strength (lateral): Before aging	Nail-holding strength (lateral): After aging
Inch	*Lb./cu. ft.*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Inches*	*Inches*	*Inches*	*Inches*	*Pounds*	*Pounds*
BOARDS MADE FROM CROP PLANT WASTES AND WASTE PAPER [2]											
0.49	16.9	14.3	11.1	11.3	9.0	0.72	0.93	0.76	1.14	74	63
.49	25.6	33.3	26.5	32.5	28.0	.85	1.02	.72	.86	143	115
.51	16.5	10.5	7.8	12.1	8.7	.54	.56	.57	.57	64	50
.51	15.7	17.2	11.0	11.3	4.7	.52	.75	.57	.71	67	54
.48	18.2	15.3	12.7	14.5	12.1	.98	1.70	1.05	1.47	83	64
[4] .53	21.8	20.5	21.1	20.7	22.3	1.27	1.06	1.32	.93	112	115
BOARDS MADE OF WOOD FIBER [2]											
0.50	16.2	16.5	12.5	13.0	10.6	0.60	0.77	0.72	0.85	72	61
[4] .52	16.9	25.4	17.1	18.0	13.8	.54	.79	.64	.81	95	75
.53	16.6	20.6	17.7	15.6	14.3	.52	.75	.68	.87	87	79
.51	18.8	17.0	13.4	16.9	12.4	.34	.39	.37	.39	71	62
[5] .47	16.5	9.7	5.6	10.5	6.2	.50	.43	.48	.59	57	31
.55	17.0	12.2	10.9	11.4	10.5	.55	.77	.50	.72	87	70
INTERIOR-FINISH BOARDS WITH SPECIAL SURFACING ON ONE SIDE [2]											
0.47	21.0	14.4	10.1	14.0	9.5	0.61	0.83	0.89	0.92	72	59
.48	16.9	15.1	10.0	11.4	10.1	.83	1.27	.89	.90	79	70
.46	20.7	12.0	9.6	12.1	10.0	.77	.88	.97	1.07	94	75
.50	17.2	16.2	15.2	13.1	11.8	.71	.79	.72	.86	70	67
.49	18.3	16.4	12.4	14.1	11.6	.98	1.37	1.10	1.35	87	64
FIBER SHEATHING BOARDS [6]											
0.74	17.8	13	10	11	10	0.31	0.30	0.28	0.30	98	90
.74	15.8	13	12	12	12	.75	.90	.71	.81	105	99
.83	20.0	48	43	45	37	.48	.55	.45	.55	171	147
[1] .81	17.0	38	33	28	26	.69	.69	.63	.72	103	80
.78	18.2	27	22	25	22	.33	.37	.39	.52	109	96
.74	19.3	45	38	40	32	.28	.32	.32	.39	135	118
.80	17.2	52	42	45	40	.48	.43	.51	.44	145	120
[8] .77	23.3	33	14	30	14	.29	.30	.29	.30	159	72
[8] .82	19.5	43	18	46	20	.36	.58	.44	.68	144	96
[8] .74	21.5	27	18	20	11	.43	.58	.54	.46	156	138

[1] Data on fiber sheathing boards taken from table 1, Report BMS 69 (*5–11*); the balance of the data taken from table 1, Report BMS 50 (*5–10*).

[2] Cycle consisted of: Immersion in water for 1 hour; spraying with condensed steam at 90° to 95° for 3 hours; storing at —12° C. for 20 hours; heating at 100° C. in dry air for 3 hours; again spraying with condensed steam at 90° to 95° C. for 3 hours; and heating in dry air at 100° C. for 18 hours. Cycle treatment continued for 300 hours.

[3] For specimens 3 inches wide on supports 12 inches apart, loaded at the center.

[4] Impregnated with asphalt.

[5] Treated with wax.

[6] Cycle consisted of: Heating at 65° C. in dry air for 3 hours; immersing in water at room temperature for 3 hours; and freezing the wet boards at —12° C. for 18 hours. Cycle treatment continued for 600 hours.

[7] Kraft paper cemented to each surface with asphalt.

[8] Two-ply laminated boards. The plies separated under accelerated aging treatment.

result of condensation in the walls, the strength of fiberboards after such exposure should be determined before specifying their use. The effects of accelerated aging on several fiberboards are shown in table 5–5.

The thicker fiberboards are sometimes used to replace lumber sheathing. Tests on conventional frame walls sheathed with fiberboard approximately ¾-inch thick (*5–5*) and subjected to racking loads indicated that for walls without openings, they were intermediate in strength and stiffness between walls with horizontal wood sheathing and walls with diagonal wood sheathing. In walls containing a window and door opening and cut to fit around the openings, the fiberboard failed at the re-entrant angles at relatively low loads. By installing the fiberboard in continuous sheets without re-entrant angles, this type of failure was prevented, the same rigidity as before was retained, and the strength was increased about 30 percent. Doubling the conventional nailing of the fiberboard in the wall with openings resulted in no appreciable increase in stiffness, but increased the strength by about 25 percent.

A fiberboard-sheathed wall tested after 1 month's exposure to high humidity lost about 15 percent of its strength and stiffness as compared with a wall tested dry.

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PROTECTION OF WOOD FROM DECAY, INSECTS, FIRE

6.0. General.—Wood, while an excellent building material, must be safeguarded from damage by insects, decay fungi, and fires. In most cases, such damage is the result of carelessness or faulty construction. Precautions for avoiding the deterioration or destruction of wood in buildings need not be expensive.

Since decay-producing fungi (sec. 2.39) cannot work in wood that has less than 20 percent moisture content, the simplest means of protecting wood from them is to keep it dry. There is no such thing as "dry rot." There are, however, a few fungi which, like termites (sec. 3.82), can grow from moist soil or wood into dry wood by taking their water with them. Two of these fungi sometimes cause great damage to buildings, but fortunately most wood-decay fungi can grow only in wood that is already damp.

Wood buildings that are properly constructed and carefully maintained are in little danger of attack by decay fungi or insects. For protection against decay, it is of utmost importance that the wood in a house be installed and maintained in a dry condition. Where this is not practicable, the wood can be protected by careful treatment with a good wood preservative. The best practice is to use wood that has been pressure treated with a good preservative in places where it is especially exposed to decay hazards (sec. 6.2). Approved methods of preservation treatment are given in Federal Specification TT–W–571b, Wood Preservative; Recommended Treating Practice, dated April 29, 1941; and in American Wood-Preservers' Association Standard 50d, Recommended Practice for the Use of Pressure Treated Lumber in Protecting Buildings Against Decay and Termites. Superficial application of wood preservative, as by brushing, spraying, or dipping, seldom provides adequate protection for wood that is exposed to conditions favorable to decay. Such application, however, does have some value in retarding the start of decay. The rate of decay after infection occurs is probably not at all decreased by surface treatments. Dip applications are useful for the treatment of window sash and other millwork that is exposed to intermittent wetting and thus to a limited decay hazard. They should not be used for the treatment of wood that is to be in contact with the ground.

Protection from fire hazards (sec. 3.83) is likewise more a matter of careful construction and maintenance than of expensive protective treatments and installations. Because the protective measures aimed at minimizing fire danger differ from those devised for elimination of decay and insect attack, fire-hazard elimination is treated separately (sec. 6.3).

6.1. CONTROL OF DECAY, INSECTS.[1]

6.10. Drainage.—Building sites should be well drained. The soil surface should slope away from the building and down-spouts should discharge into concrete or tile gutters that carry the water several feet from the house. Dense plantings close to the house impede drainage. If concrete-floored basements are not to be provided, the ground that remains moist despite drainage may be covered with a 2-inch layer of gravel before first-floor joists are installed.

6.11. Foundations.—Although the termite hazard is relatively unimportant in some northern States, in most of the country foundation walls and piers should be so built that termites cannot get through. Poured concrete gives the surest protection as long as no cracks develop. Block or brick walls or piers should have all joints well filled with cement mortar and capped with a continuous slab of reinforced concrete 4 inches thick (fig. 6–1). Walls containing voids should be faced with cement down to the footings. Termite shields near the top of the foundations are an excellent added safeguard if properly installed, but are not generally advised because carelessness in using them

[1] The material in this section was prepared by the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture. The information on insect damage is based on research by the Division of Forest Insects, Bureau of Entomology and Plant Quarantine.

usually limits their value. A detail for making the shields effective is shown in figure 6–2.

Embedding wood in concrete is an invitation to trouble. Wood posts on concrete floors should be protected from moisture by placing them on raised concrete bases and keeping them from direct contact with the concrete by asphalt paint or other waterproof coating, or by putting a piece of heavy asphalt roofing under them.

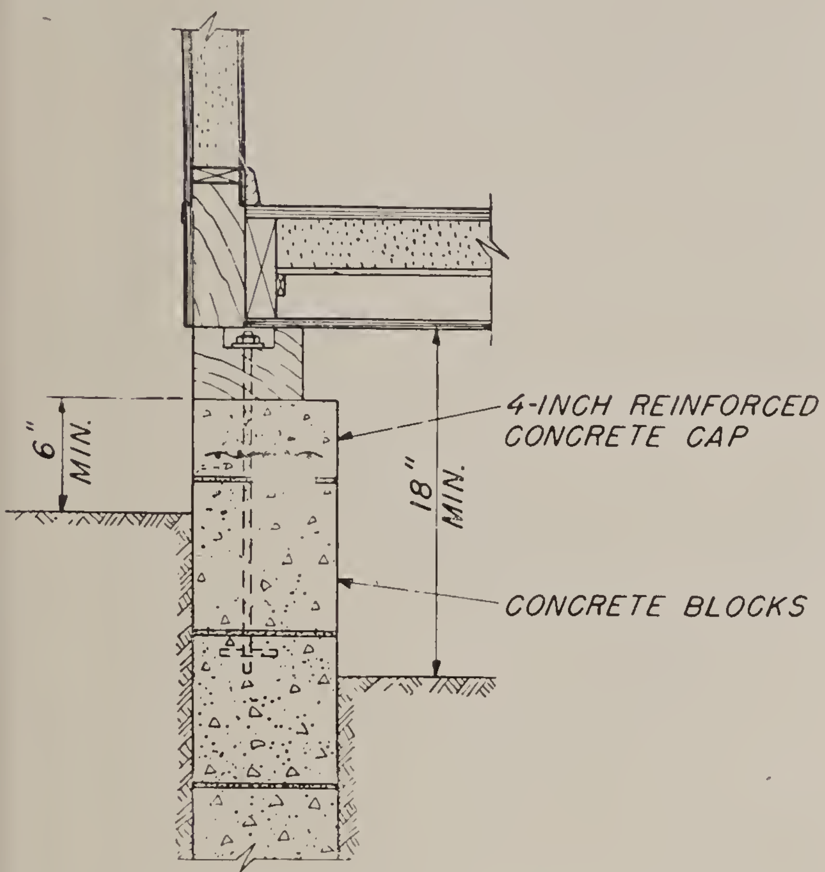

FIGURE 6–1.—Reinforced poured concrete cap on masonry walls or piers to prevent hidden attack by termites. This cap should be at least 4 inches thick and must be poured in one continuous operation to avoid joints. Brick piers should have similar concrete caps. Minimum clearance of 18 inches under the building and 6 inches outside will allow inspection for moisture condensation or decay as well as for the presence of termite tubes or for possible cracking of the cap.

If a floor is laid on a concrete slab, the upper surface of the slab should be thoroughly coated with tar or asphalt (fig. 6–3). Even with such protection, it is safest to use stringers and subflooring that have been impregnated with a good wood preservative. Expansion joints between concrete floors and foundation walls, or openings through which piping penetrates floors or walls, should be sealed with coal-tar pitch.

Dirt fills under concrete porch floors frequently provide entry for both termites and decay. It is best to build the porch as an independent unit separated from the house at all points by an air space at least 2 or 3 inches in width, with the porch floor extending over the space. A better practice is to avoid the dirt fill entirely by using a reinforced concrete slab for the porch floor.

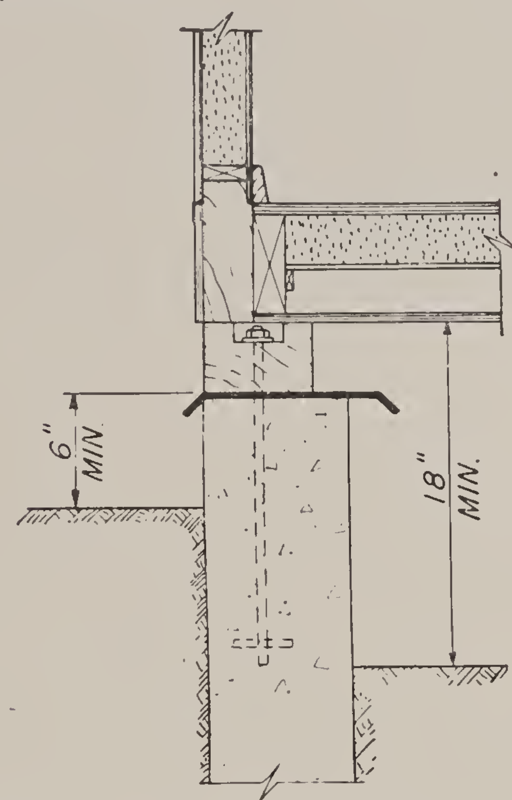

FIGURE 6–2.—Shield over uncapped brick wall.

6.12. Ventilation.—In houses without basements, a crawl space of at least 18 inches' clearance should be provided under all wood members. There should be an entrance to this space so that periodic inspections can be made. Openings in the foundation walls or skirtings should provide sufficient ventilation to keep the substructures dry. (See section 14.13.) Fire stops hinder the escape of vapor from the crawl space through walls, but this is usually desirable, since such vapor might cause troublesome condensation in the walls or attic.

6.13. Sanitation Measures.—All wood and paper scraps or old stumps should be removed from beneath the building. Concrete forms frequently afford a means of entry for both termites and decay. They should be removed.

6.14. Exteriors.—Roofs that overhang a foot or more give considerable protection to the rest of the house. If properly applied, metal flashings over window and door openings keep out water. Throughout the building, forms of construction that prevent the entrance and retention of moisture should be used.

6.15. Treatment for Powderpost Beetles.—Flooring, trim, and other hardwoods should be se-

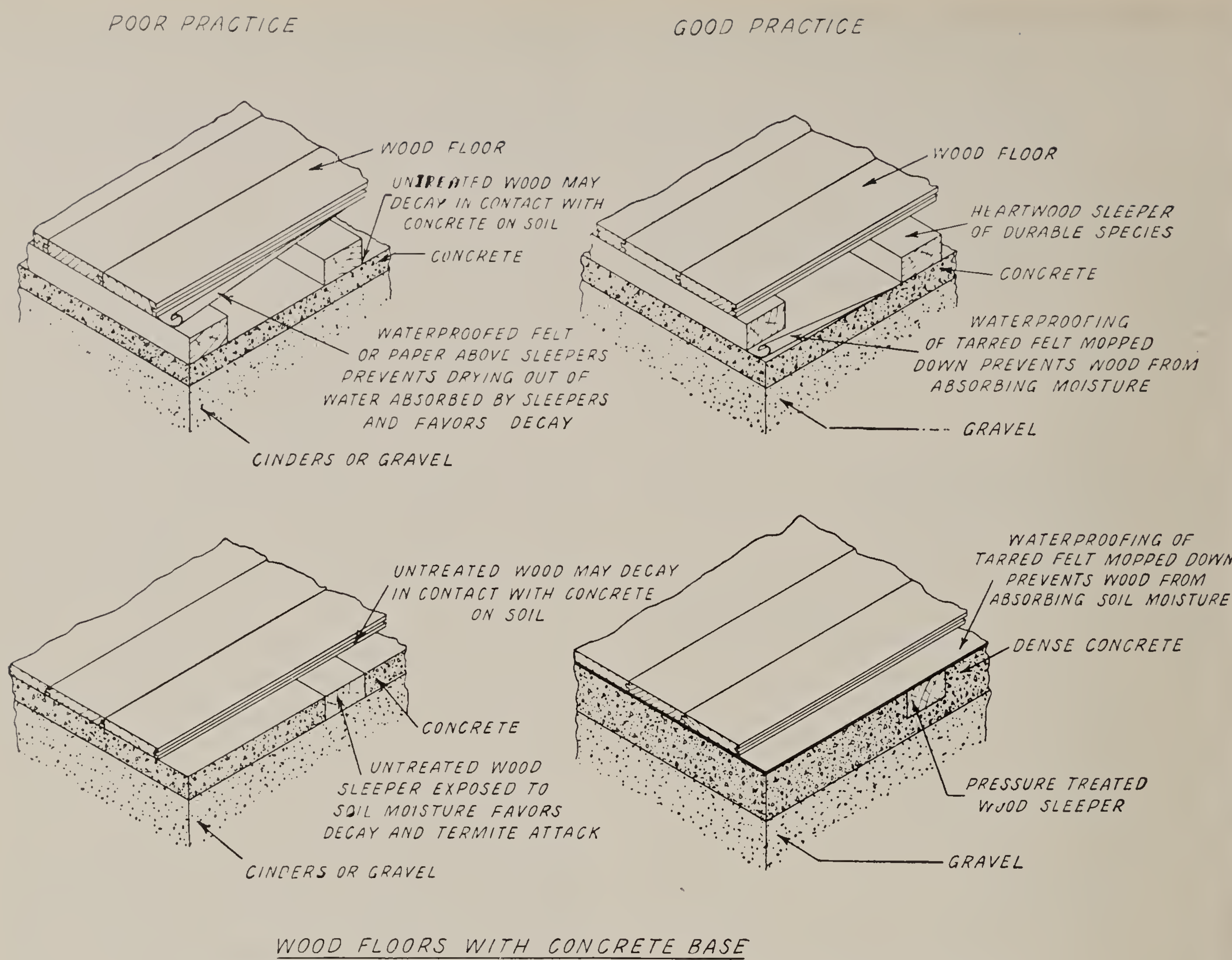

Figure 6–3.—Good and poor practice with timber on concrete or masonry.

lected from uninfested material. Whenever possible, heartwood should be selected. After wood becomes infested, saturating it with either orthodichlorobenzene or 5 percent pentachlorophenol in a light fuel oil will kill the beetles.

6.2. PRESERVATIVE TREATMENTS.—If proper construction methods are used, preservative treatment of the wood is usually not necessary. Where it is impractical to protect against excessive moisture or infection from the soil, or if the greatest possible insurance against damage is desired, preservative treatment for some parts of the building is warranted. Fully efficient preservation calls for deep impregnation. This can be secured by treatment under pressure or by cold soaking after preliminary heating.

Wood foundation timbers, footings, mud sills, plates and posts installed in contact with the ground, and wood nailing strips embedded in masonry near the ground should be pressure treated with coal-tar creosote or with a suitable substitute preservative oil. For uses where the wood will not be in contact with the ground, or where it must be painted, such as sills, or floors over unventilated slabs, pressure treatment with an acceptable water-borne preservative is generally recommended, although oil preservatives can be used provided they meet the necessary requirements as to appearance, cleanliness, odor, and paintability. Nonpressure treatments in such cases are acceptable only when they meet the preservative penetration and retention requirements called for in specifications covering pressure treatments.

Sash and millwork can be treated by dipping in an NSP (nonswelling paintable) or NSPWR (nonswelling paintable water-repellent) preservative meeting the requirements of the National Door Manufacturers' Association. It

is always desirable to have the wood cut to final dimensions before treatment. Otherwise untreated wood may be exposed by cutting, thus reducing or nullifying the value of the treatment. Where boring or cutting after treatment is required, the cut surfaces should be covered thoroughly with several brush applications of the preservative. Before installation in a building, all treated wood should be conditioned to remove the water or other preservative diluent, the presence of which would be objectionable in service. Residual water in the treated wood may cause shrinkage difficulties. Petroleum solvents remaining in the wood after treatment are likely to create complications due to odor and fire hazard and may interfere with the paintability of the wood.

6.20. Wood Preservatives.—An effective preservative must be toxic to decay fungi and harmful insects. It must also have permanence and remain in the wood during the period of use. Special requirements, such as freedom from harmful or obnoxious fumes and odor, cleanliness, paintability, and lack of fire hazard, are also important when preservatives are to be used to treat wood for houses. In addition to these requirements, the preservative must be thoroughly applied, since poor penetration and insufficient retention for the preservative usually result in inadequate protection. Preservatives for the treatment of wood in houses are of three general types: (1) Preservative oils, (2) water-borne preservatives, and (3) NSP and water-repellent preservatives.

6.200. Preservative Oils.—Preservative oils are resistant to leaching and are therefore suitable for uses where the wood is in contact with the ground. Their usefulness around houses is often limited because of such objectionable features as their odor and the difficulty in painting the treated wood.

6.2000. Coal-tar Creosote.—Coal-tar creosote is a dark-colored distillate of coal tar, heavier than water, and usually distilling between 200° and 400° C. The character of creosote varies within wide limits depending upon the properties of the coal tar, the distillation process used, and the extent to which the distillate is blended with other materials. It is essentially a byproduct of the highly diversified coal-tar industry and can therefore be expected to vary in composition according to demands for other coal-tar components. Any coal tar meeting the requirements of either Federal Specification TT–W–556a or American Wood-Preservers' Association Standard 4g can be expected to furnish a high degree of protection against decay and termites.

The principal advantages of coal-tar creosote are: (1) Its long record of satisfactory service, (2) high toxicity to wood-destroying organisms, (3) high degree of permanence under various use conditions, (4) ease of application, (5) ease of determining depth of penetration, and (6) favorable cost (when purchased wholesale).

Creosoted wood may constitute a fire hazard and be objectionable from the standpoint of odor when freshly treated. After treated wood has seasoned several months, however, these objections become less serious, since the more volatile parts of the oil disappear from near the surface and the creosoted wood has less odor and usually is but little, if any, easier to ignite than untreated wood. Food sensitive to odors, such as butter and fats, should not be stored near creosoted wood.

Wood treated with creosote or creosote mixtures can be used for structural members without appreciable odor or other disadvantage provided:

(1) No higher absorption than 8 pounds per cubic foot is used.

(2) The treated material is air seasoned sufficiently to dry the surface.

(3) No finish lumber is nailed directly to creosoted materials, since the creosote may stain the finish lumber.

(4) Plaster and lath are protected from creosoted studding with waterproof paper or nailing strips so that the creosote cannot seep along the nails to stain the plaster.

(5) Heating, cooling, or ventilating air is not circulated through enclosed spaces containing odors of creosoted wood.

(6) The treated wood is properly insulated from heat sources.

Minimum net creosote retentions of from 6 to 10 pounds per cubic foot of wood treated for use in buildings are recommended. The lower limits of this range should be employed for indoor uses.

Special grades of coal-tar creosote that are crystal-free and flow freely at ordinary tem-

peratures are available for special purposes. Such creosotes are covered by Federal Specification TT–W–560.

6.2001. Anthracene Oil.—Anthracene oils are often sold under proprietary or trade names as carbolineums, principally for nonpressure treatments. They are coal-tar distillates of higher specific gravity and higher boiling range than ordinary coal-tar creosote, but their general properties and preservative effectiveness are similar to those of coal-tar creosote. Federal Specification TT–W–531 covers anthracene oil.

6.2002. Creosote Solutions.—Creosote-coal-tar solutions and creosote-petroleum solutions are covered, respectively, by Federal Specifications TT–W–566a and TT–W–568. These solutions have had long and successful use as wood preservatives for railroad ties, lumber, and timber. For the treatment of wood for housing, however, they may be less desirable than straight coal-tar creosote, since they usually do not leave the wood surface in as clean a condition. In the case of creosote-petroleum solutions, this objectionable feature might be overcome through the use of petroleum oils that produce a solution of low viscosity and free from sludge.

6.2003. Pentachlorophenol Solutions.—Oil solutions containing 5 percent of pentachlorophenol are known to furnish good protection against decay and termites when applied by methods that assure good penetrations and retentions similar to those generally recommended for coal-tar creosote. These solutions have been used for a comparatively short time, however, so that their preservative properties have not yet been fully demonstrated. They are also effective in controlling powderpost beetles.

Pentachlorophenol itself is a crystalline material, nearly colorless. It is highly toxic to wood-destroying fungi and insects and has low solubility in water and high resistance to loss through evaporation. The penetrating properties of the treating solution, the color and paintability of the treated wood, and to some extent the protective properties of the preservative, are determined by the properties of the petroleum solvents or carriers used in the treating solution. Pentachlorophenol solutions seldom have the superior penetrating qualities that are often claimed by promoters, although oils of low viscosity should penetrate the wood somewhat better than the more viscous kinds. Solvents, such as mineral spirits, that are nearly colorless and evaporate quickly should leave the treated wood practically odorless and in a clean and paintable condition. There is some evidence to indicate that solutions prepared with light, volatile oils furnish less protection to the wood than those made with the heavier oils. For uses where the odor, paintability, and color are unimportant, heavier oils should preferably be used.

Pentachlorophenol solutions alone, or in mixture with creosote, can be applied by the conventional pressure and nonpressure methods if precautions are taken to use solvents that can be safely heated and will not cause objectionable sludging. The versatility of pentachlorophenol solutions with different solvents makes them adaptable as preservatives for a variety of uses around housing.

6.2004. Copper Naphthenate.—Oil solutions containing copper naphthenate have shown promise of providing considerable protection against decay and termites. Solution strengths equivalent to 2 percent of metallic copper have been used in superficial applications, but solutions of such concentration are likely to be too costly when applied by the more thorough impregnation methods that are needed to provide a high degree of protection. Solutions having copper concentrations of from 0.5 to 1.0 percent compare favorably on a cost basis with coal-tar creosote and 5 percent pentachlorophenol solutions, although their preservative value has not yet been fully demonstrated. Requirements as to penetration and retentions of these solutions should at least be no lower than those for creosote.

Copper naphthenate has high toxicity and good properties in regard to permanence. It imparts a green color and a characteristic odor to the wood. Some difficulty may be experienced in painting over the treated wood, especially with white paint, although this difficulty can probably be minimized through a careful selection of solvents, the use of a dryer in the treating solution, and by allowing sufficient time for the evaporation of the solvents before the paint is applied.

6.201. Water-borne Preservatives.—Water-borne preservatives are injected into the wood in water solutions. Since they are water-soluble,

these preservatives are usually less resistant to leaching and, therefore, less satisfactory than the preservative oils for uses where the treated wood is in contact with the ground or water. Some water-borne preservatives show greater resistance to leaching and therefore perform better than others under wet conditions. As a general rule, however, there is no evidence to show that the usual treatments with these preservatives will provide as good protection for wood in contact with the ground or water as does pressure treatment with coal-tar creosote. Water-borne preservatives are not recommended for superficial application as by brushing, spraying, or brief dipping. They have the important advantage of providing a treatment that enables painting of the treated wood. Some water-borne preservatives are effective fire retardants, although the flammability of the treated wood is reduced only slightly with the absorptions commonly used for wood preservation purposes only.

The water that is injected with water-borne preservatives must be removed from the wood by either air seasoning or kiln drying if shrinkage and painting difficulties must be avoided. The removal of this moisture in the wood is especially important if the treated wood is to be painted.

6.2010. Zinc Chloride and Chromated Zinc Chloride.—Zinc chloride was for many years the principal water-borne preservative used in the United States. It is clean, inexpensive, generally available, and the wood treated with it may be slightly reduced in flammability. Zinc chloride is highly soluble in water and leaches readily from the treated wood under wet exposure conditions. Because of this objectionable feature, chromated zinc chloride was developed and has come into extensive use in place of the plain zinc chloride. Laboratory and field tests indicate that chromated zinc chloride may be superior to zinc chloride in leaching properties. This superiority has not yet, however, been established conclusively. Federal Specification TT–W–571b recommends minimum net dry salt retentions of 1.0 pound per cubic foot for wood treated with zinc chloride and 0.75 pound per cubic foot for wood treated with chromated zinc chloride. Federal Specification TT–W–551 defines the composition of chromated zinc chloride, while TT–W–576a defines that of plain zinc chloride. Both preservatives are also covered by American Wood Preservers' Association Standards.

6.2011. Celcure (Acid-Cupric-Chromate).—Celcure is a proprietary preservative containing copper sulfate and sodium dichromate. Its composition is covered by Federal Specification TT–W–546. Federal Specification TT–W–571b recommends a minimum dry salt retention of 0.50 pound per cubic foot for the treatment of wood with Celcure.

6.2012. Wolman Salt (Tanalith).—Wolman salts are proprietary preservatives and may be either Triolith or Tanalith. The latter is the compound most commonly used in the United States and is recommended in Federal Specification TT–W–571b and American Wood Preservers' Association Specifications with a minimum net dry salt retention of 0.35 pound per cubic foot. Tanalith contains sodium fluoride, arsenic, sodium chromate, and dinitrophenol in proportions defined in Federal Specification TT–W–573.

6.2013. Zinc Meta Arsenite.—Zinc meta arsenite (ZMA) is a proprietary preservative covered by Federal Specification TT–W–581 and prepared by mixing a solution of arsenious acid with one of zinc acetate which contains an excess of acetic acid. Federal Specification TT–W–571b and American Wood Preservers' Association Specifications require a minimum net dry salt retention of 0.35 pound per cubic foot when lumber is treated with this preservative.

6.2014. Chemonite.—Chemonite is a proprietary water-borne preservative similar in its preservative properties to the other water-borne preservatives. Chemonite has been used to some extent for the treatment of building lumber, although it is not yet included in Federal Specifications. The proprietors of Chemonite generally apply it to the wood by pressure methods, using a net dry salt retention of approximately 0.30 pound per cubic foot.

6.202. Nonswelling, Paintable (NSP) Preservatives.—A limited amount of the woodwork in houses may at times become damp enough for fungi to become active, yet ordinarily is dry enough to be immune from attack. For such woodwork the hazard of blue stain or decay may not be great enough to warrant the expense of thorough treatment with wood preservatives. Moreover, some of the wood may be exposed to view,

where it will be finished with paint or varnish. Window sash and outside doors, which may be subject to condensation in cold weather; window and door casings; and the post, rails, and palings of porch railings and outside stairs where rain water may seep into joints and be retained for some time are typical examples of woodwork subject to moderate hazard of decay.

NSP (nonswelling-paintable) preservatives or water-repellent preservatives are available for treatment of such woodwork. They consist of fungicides dissolved in nonaqueous volatile solvents with or without the further addition of water-repellent ingredients. Suitable NSP preservatives can be applied inexpensively after woodwork has been cut, fitted, and surfaced, either just before or after assembly, without causing swelling, distortion, or roughening of the wood, without requiring careful redrying, without leaving objectionable odor, and without interfering with subsequent painting or varnishing.

Superficial treatment of wood with NSP preservatives must not be considered a substitute for sound design and construction and other precautions discussed in section 6.1. Neither can it be regarded as adequate for wood in contact with the soil or some other source of prolonged dampness for which much more thorough preservative treatment is necessary with any of the preservatives now known. The degree of effectiveness of superficially applied NSP preservatives against blue stain, decay, and insects has not been adequately established. They have been used for window sash for about a decade with, it is believed, beneficial results. On the other hand, fence posts so treated have been found to rot out about as soon as similar untreated posts. Superficially applied preservative can be recommended only for places in which untreated wood seldom succumbs rapidly enough to warrant the expense of thorough treatment but does stand enough chance of attack to justify an inexpensive treatment.

Various fungicides have been used or proposed for NSP preservatives. Those with the longest record of use for window sash and other millwork in houses are the chlorinated phenols: Pentachlorophenol, tetrachlorophenol, and chloro-2-phenylphenol. They are believed to be sufficiently effective provided they constitute not less than 5 percent of the treating solution by weight. If the preservative is sold in a concentrated form to be diluted before use, the 5 percent minimum applies to the solution after it has been diluted. More recently, phenyl mercury compounds such as phenyl mercury oleate have come into use. The minimum acceptable concentration has not yet been established but is often taken to be 0.5 percent of the treating solution by weight. Copper naphthenate at a minimum concentration equivalent to 2 percent of copper metal, or roughly 16 to 20 percent of copper naphthenate, in the treating solution by weight may be considered if there is no objection to imparting a green color to the wood and paintability with white or light-colored paints is not desired. Zinc naphthenate does not discolor wood. The minimum concentration required is about twice that for copper naphthenate, however, and for that reason the concentration of zinc naphthenate is higher than is desirable in preservatives of this kind.

The solvent in NSP preservatives usually consists chiefly of mineral spirits or Stoddard's solvent. A solvent is desired that evaporates after treatment as rapidly and completely as possible consistent with a minimum flash point of 100° F. to minimize the danger of its taking fire when used in open tanks. An aromatic type of mineral spirits or a proportion of aromatic solvent may be needed to hold the desired concentration of some fungicides in solution. A small amount of slowly volatile or nonvolatile oil, such as fuel oil, pine oil, or linseed oil, may be added to improve the penetration and spreading of the preservative through the wood structure and to prevent blooming (collection of crystals of fungicide on the wood surfaces when the solvent evaporates). Sometimes a few percent of a resin such as ester gum or cumar resin is used to prevent blooming. None of the ingredients should be liquids that swell wood.

NSP water-repellent preservatives contain, in addition to the foregoing, an ingredient that retards the rate at which the treated wood takes up moisture from contact with water. Some waxes, such as paraffin wax, in proportions of 1 to 3 percent by weight, when used as such ingredients, impart a significant though not a high degree of water repellency. Varnishes and synthetic resins in solutions having the penetrating properties required of NSP preservatives fail to impart enough water repellency to

be acceptable for that purpose. Wax alone, however, retards the drying and sometimes impairs the adhesion of coatings applied to the treated wood. If suitable resins, drying oils, or varnishes are incorporated together with the wax and if reasonable time is allowed for solvent to evaporate after the wood is treated, most of the paints commonly used on exterior and interior surfaces of houses dry rapidly enough and give good service. The water-repellent preservatives that have been widely used on window sash for some years have not given rise to difficulties with painting. For treating and finishing in a factory on a production line, however, particular care may be necessary to see that there is no interference between the water-repellant preservative and the paints or other finishes.

In order to choose intelligently among the various NSP preservatives and water-repellent preservatives on the market, it is important to know their composition, at least to the extent of the kind and proportion of fungicides used. Among makers of paints and varnish materials the term "wood preservative" is used very loosely and is sometimes applied to products that contain no fungicide at all. Enough preservatives are available in which the fungicides and their concentrations are revealed to make it unnecessary for anyone to purchase products of secret formula. It is not generally customary as yet to report in detail the nature of the water-repellent ingredients in water-repellent preservatives.

Methods of testing water-repellent preservatives for water repellency, penetration into wood, and paintability are described in Forest Products Laboratory Report No. 1495.

6.21. Methods of Preservative Treatment.—The amount of protection given by a good wood preservative depends largely upon the absorption and penetration obtained. Some methods of applying preservatives, when skillfully handled, assure satisfactory absorptions and good penetrations of the protective chemicals, while with others such results cannot be expected. The better treated products are becoming increasingly available in many sections of the country. The simple, inexpensive, and often ineffective treatments are being widely promoted, but the greater availability of well-treated lumber should tend to reduce the need for using superficial applications.

For satisfactory results with any process, the wood must be sound and properly prepared for treatment. Most processes require that the wood be seasoned either by kiln drying or air seasoning. Where such seasoning is impractical, lumber that is to be pressure treated can be conditioned by the steaming and vacuum process, the Boulton process of boiling under a vacuum, or by drying in heated vapors. These processes may be carried out in the pressure-impregnation equipment prior to the regular treatment.

Cutting, drilling, and other machining should be completed before treatment, although with wood that is to be treated with water-borne preservatives it may often be found desirable to cut to near final dimensions, treat the wood, and then season it before it is trimmed to final size. Wood treated with preservative oils does not undergo dimensional changes during treatment and can therefore be cut to final dimensions before it is treated. Timbers of Douglas-fir heartwood or other species resistant to treatment may require incising in order to take treatment satisfactorily. Incising consists of puncturing the surfaces of the piece to expose end grain and thus facilitate penetration of preservative.

6.210. Superficial Processes.—Preservative applications by brushing, spraying, or brief dipping seldom provide adequate protection for wood that is to be used under conditions favorable to decay or termite attack. Preservative solution absorptions resulting from superficial applications may vary from less than a pound per cubic foot to around 3 pounds per cubic foot and are considerably less than those obtained with the more thorough impregnation treatments. In easily treated species, such as the sapwood of ponderosa pine, preservative penetrations in the end grain may be as high as 2 or 3 inches and from $\frac{1}{16}$ to $\frac{1}{8}$ inch in side surfaces, when the wood is dipped for several minutes, as is customary in treating window sash. Penetrations resulting from superficial applications otherwise are usually shallow. Promoters of costly proprietary preservatives often recommend superficial applications as a means of reducing treating costs, and superior penetrating qualities are often claimed for some of the preservative oils. It is true that some of the

less viscous oil diluents or solvents may penetrate the wood somewhat better than the oils of higher viscosity. There is no evidence, however, to show that superficial treatments with these oil preservatives are equal to pressure treatments with either similar oils or with water-borne preservatives. No practical preservative solvent penetrates deeply and quickly into wood that is resistant to penetration.

6.211. Impregnation Processes.—Impregnation treatments are either pressure or nonpressure processes that, as a general rule, assure good penetrations and absorptions of the preservative. Some impregnation methods, principally the nonpressure processes, are less effective in producing good penetrations and in controlling preservative absorptions than others. Even the pressure processes do not produce satisfactory results if unskillfully applied or if used with woods that resist treatment.

6.2110. Nonpressure Impregnation Processes.—Of the nonpressure impregnation processes, the hot-and-cold bath method with coal-tar creosote usually produces the results that most nearly approach those obtained in pressure processes. The wood is heated in the preservative for several hours, during which time the air in the wood is expanded and partially removed. The wood may be transferred from this heating bath to a tank containing creosote at a lower temperature, it may remain in the same heating bath while the preservative cools, or the hot preservative may be drained out and the same tank quickly refilled with cold creosote. As the cooling of the wood occurs the air remaining in the wood contracts and the partial vacuum resulting causes the creosote to be forced in by atmospheric pressure. This process can also be used in applying other oil preservatives or water-borne preservatives that can be safely heated. For those that cannot be heated without decomposition, serious evaporation losses, or a fire hazard, the process may be modified to use warm air, steam, or a nonpreservative oil as the heating medium before the wood is immersed in the cold preservative. Several of these adaptations of the hot-and-cold bath process are covered by existing patents. When the wood is steamed or heated in nonpreservative oils, care must be taken to avoid excessive dilution of the preservative with water or heating oil.

The cold-soaking method with oil solutions containing adequate proportions of creosote, pentachlorophenol, or copper naphthenate, and the steeping method with such water-borne preservatives as zinc chloride, are special purpose processes suitable for use on easily treated woods, such as the sapwood of the pines. Such woods may absorb a sufficient quantity of preservative and may be well enough penetrated after soaking a few days to have good protection against decay and termite attack. Wood that is cold-soaked with preservative oils must be thoroughly seasoned before treatment, while that treated by steeping in water-borne preservatives may be treated in either the unseasoned or partially seasoned condition.

6.2111. Pressure Impregnation Processes.—Pressure processes usually have the advantage over nonpressure methods in that they make it possible to get deeper and more uniform penetration and higher absorptions of preservative and thus provide greater protection to the wood. In pressure treatment it is also much easier than in nonpressure treatments to control preservative retentions.

Pressure processes that are most effective are those involving the use of closed retorts or cylinders. Such processes are essentially alike in their principal features and differ mostly in the operating procedures employed. In the full-cell (Bethel or Burnett) method, for example, the wood is subjected to an initial vacuum, while in the Rueping (empty-cell) process the wood is impregnated with the preservative after first being subjected to an initial air pressure. In the Lowry (empty-cell) process the wood is impregnated with preservative without using an initial air pressure or initial vacuum. These variations in initial air pressures are employed to control penetrations and the quantity of preservative retained by the wood. With the full-cell processes using an initial vacuum, preservative retentions in easily treated woods may be from 20 pounds to 35 or more pounds per cubic foot. Retentions in the empty-cell processes usually vary from 4 pounds to 12 or more pounds per cubic foot depending upon the intensities of the initial air pressures used. Treating-plant operators can usually best determine from experience what treating conditions are

necessary to meet specification requirements as to penetration and absorptions in treating various woods and wood products. They should therefore be delegated with the responsibility for the selection of the treating conditions, provided, of course, that they obtain the desired results without harmful effects to the wood.

6.22. Blue Stain in Wood.—Blue stain is caused by fungi that grow in sapwood and use parts of it for their food. It is not a stage of decay, although the conditions that favor blue staining also very often lead to infection with decay-producing fungi. For this reason, lumber should be protected from blue stain. Excepting toughness, blue stain itself has little effect on the strength of wood.

To prevent blue stain, it is necessary to produce unfavorable conditions for the development of the causal fungi. These fungi are disseminated either by spores, which are produced in great abundance and are carried about by wind and insects, or by direct growth from infected to uninfected wood. Their growth is dependent upon proper food, moisture, air, and favorable temperatures. If any one of these factors can be rendered inadequate or unfavorable, sapwood will not stain.

The wood can be made unsuitable as food for fungi by introducing chemicals into it that are toxic to the fungi. This method of controlling stain in green lumber is used widely. The blue-stain fungi cannot grow in wood that has a moisture content of less than 20 percent nor in wood in which the cell cavities are absolutely full of water. Hence, the spread of stain can be prevented by rapidly drying freshly exposed surfaces to a moisture content below 20 percent. Blue-stain fungi grow most rapidly when the temperature is from 75° to 85° F. If the temperature of the wood is below 35° F. or above 100° F., no stain is likely to take place.

Several effective chemicals for treatment of lumber to prevent blue stain are available on the market. For maximum effectiveness and safety in handling them, directions of the distributors should be carefully followed.

6.3. CONTROL OF FIRE HAZARDS.

6.30. Need for Control.—In the average home the fire hazards are not great, and the probability of a serious fire occurring in any one dwelling is relatively remote. This does not mean, however, that the matter of controlling or reducing fire hazards in each dwelling should be neglected. House fires generally start and spread because of combustible contents kept in the building or because of certain structural features of the house. Correction of abnormal fire hazards associated with features of construction is definitely the concern of the prefabricator. Where contents of the home comprise the fire danger, the remedy is the responsibility of the occupant.

Some of the new and untried materials that are being proposed for use in housing are of extremely light-weight construction. Both the newness and light weight of these materials give rise to questions as to the potential fire hazards that may be introduced with their extensive adoption for housing. Obviously, therefore, the flammability and fire resistance of these new elements of construction should be given consideration.

The basic principle of fire protection is that of safety to life and property, with due consideration given costs. Such factors as suitable exits in the structure, the time necessary for fire protective apparatus to reach the scene of the fire, materials of construction, and structural design all bear upon the general problem of fire protection.

6.31. Fire Resistance of Housing.—The details of construction that provide maximum safety against the start and spread of fire are well known in locations or communities where building codes operate and are rigidly enforced.

Fires sometimes start because insufficient clearance has been allowed between combustible elements of construction and various sources of heat. Building codes specify clearly the minimum clearances permissible between combustible construction and chimneys, flues, fireplaces, smoke pipes, and various heating appliances. The clearances may vary in different locations but are of such magnitude that there is little danger of the combustible material becoming ignited.

6.310. Ignition Temperatures.—Authorities are not agreed on the minimum temperature at which wood or other cellulosic material will ignite. The technical literature frequently gives values in the neighborhood of 480° F. as the ignition temperature of wood. Actually, the ignition temperature may vary over a wide range and be influenced by the duration of ex-

posure to the elevated temperature, moisture content of the wood, density of the material, dimensions of the unit, character of surface, circulation of air, and similar factors. Exposure to temperatures not greatly in excess of 212° F. has been sufficient to carbonize wood after a few years, but failed to cause ignition. On the other hand, there are reports of spontaneous fires in buildings where wood in confined areas was exposed to temperatures that probably did not exceed 212° F. The National Fire Protection Association considers it good practice to so install heating devices that under conditions of maximum heat the temperature of exposed woodwork will not exceed 160° F.

6.311. Fire Stopping.—It is most important that fires once started be confined to the room or rooms in which they originate, so they may be extinguished readily or be prevented from involving the entire structure.

Fire started in a dwelling spreads by the movement of high-temperature air and gases through every open channel. In addition to halls, stairways, and other large spaces, these heated gases follow the concealed spaces between floor joists and between studs in partitions and walls of frame construction. Though fire usually spreads much faster vertically than horizontally, it is important that all hidden channels be obstructed at suitable points to prevent both lateral and vertical spread. The process is called fire stopping.

Vulnerable spots in frame construction that require protection by fire stops are exterior walls, partitions, stairs, pipes and ducts, sliding doors, and exterior cornices.

The fire stop may consist of 2-inch stock cut to fit tightly in the rectangular space between studs or joists, or it may be of incombustible material such as concrete, plaster, mortar, cinders, hollow tile, brick, gypsum block, or mineral wool. The fire-stopping material should not only fill completely the spaces in walls and partitions opposite hollow spaces in floors but should extend at least 4 inches above floors.

6.312. Fire Resistance of Walls, Floors, Ceilings.—Fire started in a room may be prevented from spreading to other rooms for a limited period when the fire resistance of the walls, floor, and ceiling is sufficiently high. Fire resistance in this sense refers to the length of time that the wall, floor, or ceiling will withstand exposure to a fire of definite and specified character, without disintegrating, transmitting excessive temperature, or permitting the passage of flame or hot gases.

Fire-resistance ratings are established for different types of construction by subjecting units of each construction to standard fire-resistance tests. The test devised by the American Society for Testing Materials is known as "Designation C 19–41: Standard Methods of Fire Tests of Building Construction and Materials." This test is approved by the American Standards Association as American Standard "ASA No. A–2.1—1942."

Briefly, the manner of conducting the test is to expose one side of the assembly to furnace temperatures that reach:

1,000° F. at 5 minutes
1,300° F. at 10 minutes
1,550° F. at 30 minutes
1,700° F. at 1 hour
1,850° F. at 2 hours
2,000° F. at 4 hours
2,300° F. at 8 hours and over.

For walls, partitions, floors, and ceilings the transmission of heat through the assembly is considered excessive when the average of observed temperatures on the unexposed surface exceeds the initial temperature by 250° F., though a rise of 325° F. is tolerated at any one point of observation.

The construction unit may or may not be tested under bearing loads. The test may be supplemented or followed by a hose-stream test which subjects the burned assembly to the impact, erosion, and cooling effects of a specified stream from a fire hose.

Performance of the various elements of construction under the standard fire test is the accepted criterion for the fire resistance required by various building codes for structures of a given type and occupancy. A proposed uniform code is being drafted on performance requirements which permit the use of any form of construction that will resist a specified fire exposure.

Few data are available that permit comparisons as to how actual building fires compare with the test fires controlled by the standard time-temperature curve. The National Bureau of Standards has, however, conducted large-scale complete burn-out tests of rooms in fire-

resistance test houses fitted with combustible contents. With these data and those obtained from actual surveys of the combustible contents associated with representative types of occupancies or buildings, this Bureau has attempted to correlate the severity of the fire with the amount of combustible contents. The approximate relation of the amount of combustibles to the fire severity as published in the Bureau's Building Materials and Structures Report No. 92 is given in the following tabulation. The weight of various combustible materials was recalculated when necessary on the basis of a fuel having a calorific value of 8,000 British thermal units per pound of dry material.

Average weight of combustibles (Lb. per sq. ft. of floor area)	Fire severity (Hours)
5	½
7½	¾
10	1
15	1½
20	2
30	3
40	4½
50	6
60	7½

In apartments and residences the amount of combustibles, including combustible floors and woodwork, was found to be uniformly light and to average less than 10 pounds per square foot of floor area. A complete burn-out of contents, according to the Bureau of Standards calculations, would be equivalent, on this weight basis, to a fire severity of less than 1 hour.

Various building codes require specific minimum fire-resistance ratings for multiple dwelling units. For one- and two-family frame dwellings, however, there are no uniform restrictions other than those which the builder or local building inspector may require.

There are more resistance data available for partition walls of different types than for exterior walls, floors, and ceilings of frame construction. The fire resistance of some typical hollow-partition walls in which different materials are applied to both sides of wood studs is given in National Bureau of Standards Building Materials Standard No. 71 as follows:

Type of facing on wood studs	Fire resistance (Minutes)
Expanded metal lath with ¾-inch thick gypsum plaster	60
Wood lath with ½-inch thick gypsum plaster	30
Plaster board with ½-inch thick gypsum plaster	30
⅜-inch gypsum wallboard	24½
½-inch fiberboard	9½ to 16½
1-inch T&G pine ceiling	23
¼-inch exterior plywood	12
⅜-inch exterior plywood	18
½-inch exterior plywood	25

6.32. Improvement in Fire Resistance.—The variation in fire resistance for different types of partition walls shows that the fire resistance of walls may vary with the choice of facing materials and the thickness of some of the facings selected.

6.320. Insulation.—The fire resistance of a specific type of wall or partition may be materially increased by the use of insulation between the stud spaces. The amount of increase will depend upon the type of insulation chosen and the density at which the space is filled. Approximate values for different types of partition walls are given in table 6–1, as determined by tests at the Forest Products Laboratory and National Bureau of Standards.

Table 6–1.—*Fire resistance of insulated partition walls*

Kind of facing on wood studs	Kind of insulation in stud spaces									
	None	Reflective (double-faced)	Shredded paper 0.7 lb. per sq. ft	Shredded redwood bark		Cellulosic blanket 0.35 lb. per sq. ft.	Mineral wool batts (Lb. per sq. ft.)			
				0. lb. per sq. ft.	1.7 lb. per sq. ft.		0.5	1.0	1.5	2.0
	Min.	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*
¼-inch interior plywood	10	18	--------	33	51	17	------	34	40	50
¼-inch exterior plywood	12	24	--------	36	63	18	29	40	43	60
⅜-inch interior plywood	17	23	--------	--------	--------	24	------	45	55	60
⅜-inch exterior plywood	19	25	33	--------	--------	31	------	50	60	72
½-inch interior plywood	22	--------	--------	--------	--------	27	------	------	------	------
½-inch exterior plywood	25	--------	--------	--------	--------	37	------	------	------	------
½-inch gypsum wallboard	41½	--------	--------	--------	--------	--------		51 to 66		
½-inch plaster on wood lath	38	--------	--------	--------	--------	--------		73 to 91		
¾-inch plaster on metal lath	60	--------	--------	--------	--------	--------		95		

As an example, table 6–1 shows that mineral-wool insulation installed in the stud space at a density of about 1 pound per square foot of wall area increased the fire resistance of a 3/8-inch exterior plywood-faced wall from about 19 to 50 minutes. Mineral-wool insulation filled at a density of 2 pounds per square foot increased the resistance of the same type of wall panel to more than 1 hour.

It must be remembered, however, that fire resistance is based upon the performance of the weakest part of the assembly. The insulation must be installed uniformly throughout the stud spaces. Uniformity of fill is more readily secured with batt insulations than with blown insulation which tends to arch over nails or other projections within the walls and produce voids. It is especially important in the case of prefabrication that the joints between units have as much resistance as other parts of the assembly. Poor or careless workmanship during assembly, moreover, may be responsible for a lower fire resistance than would be reasonably expected.

6.321. Treatments to Increase Fire Safety of Wood.—The spread of small or incipient fires beyond a small localized area may be prevented, or the rate of spread greatly retarded, if the combustible materials immediately adjacent have received an adequate treatment with fire-retarding chemicals. These treatments, designed essentially to reduce the flammability of wood, fall into two general classes: (1) impregnation treatments and (2) surface coatings.

Unfortunately the standardization of methods for evaluating the effectiveness of fire-retarding treatments has not been developed to the same extent that it has for fire-resistive construction. Extensive records of the performance of different treatments in building fires are lacking. Minimum test requirements for impregnation treatments, however, have been more clearly established than they have for coatings.

6.3210. Impregnation Treatments.—To obtain the fire-test performance currently considered desirable for impregnated lumber, it is necessary that specific minimum amounts of fire-retarding chemical be deposited within the wood. As most woods do not, however, readily absorb enough water solution by surface applications, dipping, or soaking, it is necessary to resort to injection by vacuum-pressure methods. Such processes require suitable plant facilities and technical skills to produce satisfactory results, and accordingly the treatments must be made before the material is delivered on the job site. The plant treatments are usually made to special order according to recognized specifications. This class of material is rarely stocked by local lumber yards.

The cost of pressure-impregnated, fire-retardant lumber will be influenced by a number of factors, but in sizes suitable for home construction is likely to approximately double that of untreated lumber.

The two check-test methods in current use for evaluating the effectiveness of impregnation treatments are American Society for Testing Materials Standards E 160–46, Test for Combustible Properties of Treated Wood by the Crib-test Method; and E69–46T, Test for Combustible Properties of Treated Wood by the Fire-tube Test Method. Evaluations have been made also by the fire hazard classification test described in Research Bulletin No. 32 of the Underwriters Laboratories, Inc.

6.3211. Fire-retarding Coatings.—Numerous preparations offering fire-retarding effects to varying degrees have been proposed. As in the case of impregnation treatments, the degree of protection secured is related to the inherent properties of the preparation, thoroughness of application, and the severity of the fire exposure.

General agreement upon standard methods for evaluating the effectiveness of fire-retarding coatings has not reached the stage it has for impregnation treatments. Some of the methods proposed are described in Research Bulletin No. 32, Fire Hazard Classification of Building Materials, by Underwriters Laboratories, Inc.; Federal Specification SS–A–118, Acoustical Units; Prefabricated; and Forest Products Laboratory Report No. 1443, Fire Test Methods Used in Research at the Forest Products Laboratory.

In the following discussion of fire-retardant coatings, the grading has been based largely upon performance exhibited in the fire-tube test, the Schlyter test described in Forest Products Laboratory Report No. 1443, and by performance in the test included in Federal Specification SS–A–118

6.32110. Solutions.—Solutions of a sodium silicate (water glass) either alone or in combination with inert materials have formed the basis of many proprietary fire-retarding paints. The protection given by a sodium silicate solution is due largely to its property of intumescence; that is, when the silicate coating is exposed to heat it swells to a frothy mass which provides the underlying wood with insulation against heat. The serious weaknesses of sodium silicate as a fire-retarding coating are its instability when exposed to dampness and the fact that carbon dioxide in the air eventually converts it to sodium carbonate and silica, neither of which intumesces upon exposure to heat. While fresh, however, sodium silicate coatings are very effective against small fires. The pigmented preparation given below was recommended during World War II (in a publication of the British Air Raid Precaution Series 39, February, 1940) as a protection for attics against incendiary bomb fires and for evaluating the effectiveness of other fire-retarding preparations:

Sodium silicate solution (specific gravity 1.41 to 1.42; silica-soda ratios 3.2 to 3.4)	112 pounds
Kaolin	150 pounds
Water	100 pounds

One gallon of this preparation covers approximately 100 square feet in four coats.

Plain water solutions of effective fire-retarding chemicals, such as monoammonium phosphate, diammonium phosphate, and mixtures of ammonium sulphate and monoammonium phosphate, borax and boric acid, and other formulations used for impregnating lumber, have been promoted as fire-retarding coatings. While strong solutions may possess inherently good fire-retarding properties, the effectiveness of their application will depend upon the amount of chemical retained by the wood. As most woods will absorb only a relatively small quantity of solution with a single brush application, the degree of protection secured by such treatment is low. Only by several applications of strong solution of these chemicals can even a moderate degree of fire-retarding effectiveness be obtained.

Most of the fire-retarding paints have fire-retarding chemicals incorporated in various types of vehicles. Usually, to obtain satisfactory fire-retarding effects, such paints must be applied to wood in considerably greater thickness than is customary with purely decorative paints.

6.32111. Linseed Oil-base Paints.—Linseed oil-base paints of good fire-retarding effectiveness have been prepared at the Forest Products Laboratory by replacing a material portion of the pigment with finely ground borax. Table 6–2 gives four types of single pigment formulation.

Heavy coatings of this type of paint, or a coverage of about 125 square feet per gallon, are required to afford the better degrees of protection against spread of flame.

TABLE 6–2.—*Borax-linseed-oil fire-retardant paint formulas*

Chemical	Formula No. 1	Formula No. 2	Formula No. 3	Formula No. 4
	Percent [1]	*Percent* [1]	*Percent* [1]	*Percent* [1]
White lead [2]	41.0			
Titanium-calcium		30.0		
Lithopone			24.0	
Zinc oxide				21.0
Borax	32.0	35.0	39.5	50.0
Raw linseed oil	22.8	30.8	32.3	24.8
Turpentine	3.6	3.6	3.6	3.6
Japan drier	.6	.6	.6	.6

[1] By weight.
[2] Basic carbonate white lead.

6.32112. Alginate Paints.—In a newer type of coating developed at the Forest Products Laboratory, an aqueous gel of sodium or diammonium alginate is employed as the vehicle. The use of the alginate makes it possible to incorporate into the preparation a quantity of fire-retardant chemical considerably in excess of that required to saturate the solution. Care must be taken, however, in the selection of the fire-retardant chemical. The ammonium fire-retardant salts and mixtures of borax and boric acid are compatible with the gel, but many metallic salts, including borax alone, cause the gel to set. Suitable pigment may be added to improve opacity or give desired tints. A simple formulation of this type of preparation consists of 50 parts by weight of monoammonium phosphate and 50 parts by weight of 2 percent sodium alginate gel.

The body of the preparation is such that sufficient dry fire retardant can be applied in two or three coats to give excellent protection against spread of flame.

6.32113. Methyl Cellulose Preparations.—Preparations similar to the borate-alginate prepara-

tions may be made by using methyl cellulose as the thickening agent or vehicle. It may be used with borax, boric acid, or mixtures of borax and boric acid, but not with ammonium phosphate, as the latter salt causes coagulation.

Three typical methyl cellulose preparations are indicated below:

	Parts by weight		
Borax ($Na_2B_4O_7.10\ H_2O$)	50	—	30
Boric acid	—	50	30
2 percent methyl cellulose....	50	50	40
	100	100	100

6.32114. Synthetic-resin Formulations.—Certain combinations of urea-formaldehyde resins and ammonium phosphate provide excellent protection against flame spread. Such coatings owe their effectiveness to the intumescence of the resin upon exposure to heat, and protection against combustion of the charred frothy mass is furnished by the ammonium phosphate present.

6.32115. Casein and Whitewash Paints.—Casein and whitewash paints are generally regarded as having fire-retarding properties, especially when applied in heavy coats. The degree of protection is increased when borax is introduced in the formula, but even then three coats of such preparation are not of the same effectiveness as three coats of the borax-linseed oil paint, sodium-silicate, phosphate-alginate, or synthetic-resin formulations.

6.32116. Magnesium Oxychloride and Oxysulfate Coatings.—Fire-retardant coatings made by mixing magnesium oxide (magnesite) with a solution of magnesium chloride or magnesium sulfate provide good protection against flame spread when applied in heavy coats (100 grams of dry coating per square foot of surface). They are likely, however, to absorb moisture and soften even at comparatively low atmospheric humidities.

6.32117. Water Insoluble Fire-retardant Preparations.—One inherent major weakness of all of the preparations described is their inability to retain their effectiveness after exposure to water, due to the removal of the water-soluble fire retardants. Some will offer slightly more resistance to moisture than others. Furthermore, fire-retardant coatings require replacement at intervals, as do paints of the decorative types. So far as known, no water-insoluble compound has been found that is equal in fire-retardant effectiveness to such water-soluble compounds as ammonium phosphate, borax, and sodium silicate. Water-insoluble compounds having moderate fire-retarding properties are zinc borate, chlorinated rubber, and chlorinated paraffin.

PAINTS AND PAINTING

7.0. GENERAL.—Although painting is usually one of the minor costs in building a house, it commonly becomes one of the principal expenses in subsequent maintenance of the house. The conscientious builder gives more careful attention to the wise choice and proper application of paints and finishes than their fraction of the construction costs might otherwise seem to justify. A disproportionately large part of the buyer's final judgment of the quality of the house is likely to be based on the performance of the paints and other finishes and the trouble and expense of maintaining them.

7.1. PURPOSE OF PAINTING.—Most painting is done primarily for decoration, that is, the improvement or modification of appearance. Opaque coatings of paint or enamel conceal the grain, color, and texture of wood and substitute color, sheen, and texture of their own. Enamel, particularly highly glossy enamel, requires careful scraping or sandpapering of the wood to remove all tool marks and raised grain before enameling, else the mirror-like qualities of the enamel will accentuate rather than conceal the uneven wood surface. Wood sealer and varnish are transparent; they reveal the grain and color of wood but modify its sheen and texture. Stain changes the color of wood without altering its sheen or texture, but stain followed by sealer or varnish modifies all three properties. Wood filler plugs the pores of hardwoods in which the pores are as large or larger than those in birch, so that smooth surface coatings can be applied; the pattern of the pores may or may not be accentuated in appearance according as a colored or a natural wood filler is used. Putty is used for filling nail holes or other gross imperfections and, of course, for glazing.

7.2. DEGREE OF PROTECTION FURNISHED BY PAINT.—Protective finishes vary greatly in the degree to which they retard the passage of moisture into or out of wood. The variation is so great that the Forest Products Laboratory finds it necessary to use two different methods of measuring protective power, the method of moisture-excluding effectiveness for the more effective kinds of coatings and the method of water repellency for the less effective coatings and treatments.

7.20. Moisture-excluding Effectiveness.—The moisture-excluding effectiveness of the more effective coatings is measured by comparing the change in moisture content of coated and uncoated specimens of wood, closely matched for species, grain, density, size, and initial moisture content, when subjected side by side to dampness for a suitable length of time. If A is the gain in weight of the uncoated and X the gain by the coated specimen, then the moisture-excluding effectiveness of the coating, E, expressed in percent, is:

$$E = \frac{100\ (A-X)}{A}$$

In other words, the coating excludes E percent of the moisture picked up by the uncoated specimens under the conditions prevailing in the test. In the procedure of the Forest Products Laboratory, the wood specimens are usually ⅝ by 4 by 8 inches in size, initially in equilibrium with 65 percent relative humidity at 80° F. (about 12 percent moisture content) and are tested by exposure for 7 days to 97 percent relative humidity at 80° F. Exterior coatings may then be exposed to the weather on test racks for successive periods of 6 months and their moisture-excluding effectiveness determined after each period.

Table 7–1 presents data for the moisture-excluding effectiveness of coatings commonly used in painting houses or chosen to demonstrate the factors in coating composition that govern protective power (*7–1*). For each item listed, E was determined after applying each one of three coats and then after the coated specimens had been exposed to the weather for successive intervals of 6 months until the coating failed seriously. The data illustrate the following general principles, which are sub-

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stantiated by much experimental work during the past 30 years.

(a) No material affords good protection when only one coat is applied. Clear liquids, containing no pigments, are so low in effectiveness that the milder water-repellency test must be used to evaluate them satisfactorily. Materials containing pigments are more effective than clear liquids in single application. Occasionally one application of a pigmented coating seems moderately effective, as indicated by items 17 and 21 in table 7–1, but they do not yield such results consistently in practice.

(b) A second coat usually increases the moisture-excluding effectiveness greatly, provided that the first coat remained near and sealed the surface of the wood. Effective protection is furnished by a continuous coating over the surface of wood rather than by filling wood cavities with paint oils or paint. In table 7–1, two coats of linseed oil (item 1) are shown to be little better than one coat, because raw

Table 7–1.—*Moisture-excluding effectiveness of coatings selected to demonstrate factors that govern protective power*

Item number	Description	Effectiveness [1] after applying number of coats indicated but before exposure to the weather: 1 coat E_0	2 coats E_0	3 coats E_0	Effectiveness of 3 coats after exposure to the weather at 45° facing south at Madison, Wis., for the time in months indicated by subscripts: E_6	E_{12}	E_{18}	E_{24}	E_{30}	E_{36}	Durability [2] in months or rating for integrity after 36 months	Time in months after which the defects indicated were observed: Chalking	Checking	Cracking
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*				
	Clear coatings (containing no pigments) [1]													
1	Linseed oil containing paint drier	3	5	21	21	0	-----	-----	-----	-----	12	-------	-------	-------
2	Spar varnish made with ester gum in tung and linseed oils at 75-gallon length [3]	3	14	35	29	0	-----	-----	-----	-----	6	-------	-------	-------
3	Spar varnish similar to No. 2 except 33-gallon length	6	37	65	45	0	-----	-----	-----	-----	6	-------	-------	-------
4	Spar varnish made with phenolic resin [4] in tung oil at 50-gallon length	5	49	73	65	45	41	-----	-----	-----	18	-------	-------	-------
5	Spar varnish made with phenolic resin [4] in linseed and tung oils at 60-gallon length	4	47	66	60	34	26	-----	-----	-----	18	-------	-------	-------
	Paints made with linseed oil (item No. 1) and the pigments indicated, p/nv [5] 0.28 [1]*:*													
6	Magnesium silicate (pigment of low opacity)	10	37	55	63	43	41	5	-----	-----	24	6	-------	-------
7	Titanium dioxide (white, opaque pigment)	23	60	63	69	33	27	17	-----	-----	24	6	-------	-------
8	White lead (opaque, chemically active pigment)	20	57	70	84	76	68	54	14	24	Fair	6	12	-------
9	Zinc oxide (opaque, chemically active pigment)	36	68	75	89	85	71	51	23	19	Fair	12	-------	24
10	White lead, zinc oxide, magnesium silicate	33	71	74	90	86	82	66	34	28	Fair	12	-------	24
11	Zinc oxide, titanium dioxide, magnesium silicate	24	65	70	88	84	84	91	70	54	Fair	6	-------	30
12	Iron oxide (red, opaque pigment)	23	53	56	70	60	63	64	44	34	Good	18	-------	-------
	Enamels made with ester gum varnish (item No. 3) and the pigments indicated, p/nv 0.28 [1]*:*													
13	Magnesium silicate	30	66	83	69	25	13	-----	-----	-----	18	6	-------	12
14	White lead	24	85	91	91	49	39	13	-----	-----	24	6	-------	-------
15	Iron oxide	33	82	88	80	70	78	76	43	62	Good	6	-------	-------
	Enamels made with phenolic resin varnish (item No. 5) and the pigments indicated, p/nv 0.28 [1]*:*													
16	Magnesium silicate	30	60	78	72	64	68	56	10	10	36	6	-------	12
17	White lead	62	86	91	91	91	95	93	63	73	Good	12	-------	-------
18	Iron oxide	8	64	81	77	69	79	87	65	73	Good	6	-------	-------
	Aluminum paints made with 2 pounds of aluminum powder in 1 gallon of the vehicle indicated [1]*:*													
19	Bodied linseed oil, 67.5 percent nonvolatile [6]	14	57	77	93	73	73	77	63	61	Good	-------	-------	-------
20	Ester gum spar varnish, long oil (item No. 2)	9	61	90	96	84	84	84	76	76	Good	-------	-------	-------
21	Phenolic resin spar varnish (item No. 4)	38	88	95	97	87	87	89	85	85	Good	-------	-------	-------
22	An alkyd resin spar varnish	9	81	93	97	85	85	89	81	79	Good	-------	-------	-------
	Painting systems consisting of a priming coat of the item indicated followed by two coats of paint, item No. 8 [1]*:*													
23	Item No. 19, aluminum paint	[7] 24	75	84	90	80	80	76	56	60	Fair	6	12	-------
24	Item No. 20, aluminun paint	8	62	86	90	80	74	62	40	48	Fair	6	12	-------
25	Item No. 21, aluminum paint	39	86	91	91	85	87	77	55	61	Fair	6	12	-------
26	Item No. 22, aluminum paint	14	72	86	86	86	86	70	48	52	Fair	6	12	-------
27	Item No. 1, clear linseed oil	0	36	63	81	71	47	43	33	-----	30	6	12	-------
28	Item No. 4, clear spar varnish	2	40	62	80	72	54	42	26	-----	30	6	12	-------

[1] Each finish was tested on ⅝″ x 4″ x 8″ matched specimens of southern yellow pine, Douglas-fir, eastern white pine and redwood. Results reported for moisture-excluding effectiveness are averages for the four woods but the durability is the average for white pine and redwood.

[2] At each inspection coatings are rated good, fair, poor, or bad in integrity. The durability is the age at which they are first rated poor.

[3] A varnish made with 75 gallons of drying oil to 100 pounds of resin is said to be a 75-gallon varnish or a varnish of 75 gallon length. If there are 33 gallons of oil to 100 pounds of resin it is a 33-gallon varnish.

[4] The phenolic resin was paraphenylphenol formaldehyde.

[5] The proportion of pigments in a paint or enamel is expressed in terms of pigment volume, *p/nv*, in which *p* is the volume of pigments and *nv* is the total nonvolatile (pigments plus vehicle nonvolatile).

[6] Bodied linseed oil is linseed oil that has been thickened in viscosity by heating and then thinned with volatile thinner. In this case the bodied oil also contained drier.

[7] This is the same as the first coat of item No. 19 above, for which *E* was only 14 percent. Such discrepancies are to be expected on repeating tests of coatings of low effectiveness, particularly when only one coat is applied.

linseed oil penetrates too far into wood to seal the surfaces in one application; a third coat was required to attain continuity of surface coating and moderate effectiveness. When high effectiveness has been attained with the second coat, a third coat adds little more (items 14, 17, 21, and 25 of table 7–1).

(c) When an adequate surface coating has been formed, as was the case after the third coat in the data of table 7–1, medium to high moisture-excluding effectiveness may be attained, depending upon the nature of the coating. Clear drying oils give only moderate effectiveness, but varnishes are more effective, increasingly so the higher the proportion of resin. Varnishes made with some phenolic resins are particularly high among clear coatings. Paints and enamels, which contain pigments, are much more effective than the clear vehicles with which they are made, even when the pigments are inexpensive extending pigments; when chemically active pigments, such as white lead and zinc oxide, are used, high effectiveness can be obtained. Enamels containing both resin and chemically active pigments attain as much as 90 percent effectiveness. Aluminum pigment, because of its peculiar leafing properties, makes coatings of as much as 95 percent effectiveness.

(d) On exposure to the weather, durable coatings at first increase in effectiveness, reach a maximum, and then fall off, usually becoming low in effectiveness by the time the coating wears away to the point at which it usually should be repainted. Clear coatings need renewal frequently, perhaps once a year or even more often. Coatings containing pigments are more durable. Even the inexpensive pigments of low opacity add materially to durability, but opaque pigments add much more, especially if they are strongly colored, such as iron oxide, or chemically active, such as white lead and zinc oxide.

Painting is done also for protection of wood against adverse conditions of service. Protective coatings retard changes in moisture content and consequent changes in dimensions and shape of wood. A high degree of stabilization can be imparted to wood that is repeatedly exposed to extremes of dampness or dryness for brief periods at a time. On the other hand, coatings do not alter the equilibrium moisture content or dimensions of wood and are therefore ineffective against long-continued exposure to dampness or dryness. Exterior woodwork, which is subject to the rapidly fluctuating conditions of the weather, undergoes graying, roughening, checking, distortion, and slow wasting away at the rate of one-fourth inch a century unless it is kept protected by coatings. With thick pieces of wood firmly fastened in place, such weathering is objectionable only when the appearance is unsatisfactory; but with pieces less than one-half inch thick, weathering may cause excessive cupping and splitting. Nevertheless ½- by 6-inch bevel siding well nailed in position with corrosion-resistant nails can be expected to last 25 years or more without protection by coatings or preservatives provided the building is soundly constructed.

Interior woodwork, unless it is repeatedly wet with water, is not subject to weathering. It may be expected to last indefinitely, but its surface may roughen and it is hard to keep clean unless it is given a protective coating or finish. Dimensional stability can be improved, particularly in rooms in which cooking, laundry work, and bathing are done, by applying protective coatings; but for greatest effectiveness all surfaces of each piece of wood, including surfaces not exposed to view, should receive protection. Seasonal changes in dimensions of wood, such as the change between average summer and average winter conditions in houses that must be heated during a cold winter season, can be materially reduced only by coating procedures much more effective than are commonly deemed practicable.

Painting is sometimes done to produce more efficient and satisfactory illumination. Dark basements or poorly lighted utility rooms, for example, may be painted with inexpensive white paints in order to obtain better distribution of the limited amount of light often provided. Precaution against accidents may be an important consideration in such painting.

The percentage of moisture-excluding effectiveness is a relative figure suitable for comparing different coatings when tests are made with well-matched wood specimens according to the arbitrary method described. As the equation for moisture-excluding effectiveness indicates, the effectiveness, E, depends upon the absorptiveness of the uncoated wood, A, as well

as the resistance offered by the coating. In general, the more rapidly the wood absorbs moisture the higher is E for any given coating, and the variation in test results is greater the lower the effectiveness of the coating. Any given coating, therefore, furnishes greater protection for sapwood than for heartwood, for woods of low density than of high density, for end-grain than for side-grain wood, and often for flat-grain than for edge-grain surfaces. Since uncoated wood takes up liquid water very much faster than it absorbs moisture from damp air, coatings furnish correspondingly greater protection against liquid water than they do against high relative humidity.

Coatings do not alter the hygroscopicity of wood or the equilibrium moisture content and dimensions to which it will come if given time enough. All coatings can do is to retard the rate at which gain or loss of moisture takes place. The effectiveness of a coating, therefore, diminishes as the time of exposure to extreme dampness or dryness increases; that is, it takes a more effective coating to furnish a given degree of protection against prolonged exposure than against brief exposure. For example, in certain tests E for one dip in a water repellent was 31 percent for exposure to 97 percent relative humidity for 1 day; but by the time the exposure extended to 14 days E fell to 4 percent. On the other hand, 3 coats of aluminum paint were 94 percent effective for 1 day and were still 92 percent after 14 days but eventually the effectiveness would fall to zero if the exposure continued for a number of months.

7.21. Water Repellency.—The method of moisture-excluding effectiveness does not discriminate satisfactorily among coatings and treatments that rank below 10 to 20 percent, such as a single application of the clear coatings in table 7–1. Nevertheless, coatings or treatments of such low degree of effectiveness have found use where protection is needed for brief exposures to water or where it would be impracticable to apply and maintain surface coatings. The method of measuring water repellency requires at least 5 pairs of specimens of sapwood of ponderosa pine for each material to be tested, each pair of specimens to be taken from a different plank so that, by taking the average, variations due to peculiarities of the wood can be minimized. Specimens are ¼ inch along the grain, 1⅝ inches radially, and 8 inches tangentially to the growth rings. One of each pair of specimens is coated usually by dipping, with the product to be tested, all specimens brought to equilibrium in 65 percent relative humidity at 80° F., and the tangential dimensions measured accurately. The specimens are then immersed in water for 30 minutes, after which the tangential dimensions are again measured. The water repellency of the material tested, W, in percent is then:

$$W = \frac{100\ (S_o—S_t)}{S_o}$$

Where S_o is the sum of the swelling of each of the untreated specimens and S_t the sum of the swelling of each of the treated specimens.

Table 7–2 presents data for the water repellency of commercial products together with the water repellency and moisture-excluding effectiveness of products of known composition. The data afford a rough comparison of the scales of values for water repellency, W, and moisture-excluding effectiveness, E (*7–6*).

Two general types of products in the low range for which the water-repellency test is used are of importance in housing. Both of them penetrate into the surface of wood and are deposited in the wood cavities near the surface without forming much if any coating over the wood. One type penetrates only slightly and leaves the wood cavities nearest the surface largely filled with nonvolatile material. The other type continues to spread deeper into the wood for a day or two after it has been applied and consequently leaves the wood cavities nearest the surface still largely unfilled. The former type is properly called wood sealer, the latter water repellent, but careful distinction between them is not yet maintained in commercial practice. Sealers and water repellents must be recognized by their properties rather than by the names under which they are sold.

7.210. Wood Sealers.—Wood sealers are essentially a special variety of varnish, less often of lacquer. As indicated by the data of table 7–2, sealers contain less nonvolatile than other varnishes, 15 to 45 percent by weight, the thinners often have a flash point much below 100° F., the viscosity varies greatly but is usually less than that of other varnishes and more than that of water repellents, they usually dry rapidly to

Table 7–2.—*Water repellency and other characteristics of sealers, water repellents, and other materials for comparison*

Item number	Description	*E* Moisture-excluding effectiveness	*W* Water repellency after: 1 dip	*W* Water repellency after: 2 dips	Depth of penetration into end-grain sapwood	Paint holdout	Drying of film on tinplate (nonabsorptive surface)	Acetone precipitation test	Viscosity	Flash point	Nonvolatile content by weight
		Percent	*Percent*		*Inches*	*Units* [1]		*Milliliters* [2]	*Millipoises*	*°F*	*Percent*
XO	Three coats of phenolic-resin enamel	91	100		------	------	------	------	------	------	------
XI	Three coats of phenolic-resin varnish	73	93		------	------	------	------	------	------	------
	Commercial water repellents or water-repellent preservatives:										
3L	Water-repellent preservative	9	77	81	1¾	1	Nondrying	2.5	17	107	[3] 11.3
5L	Water repellent	------	75	------	2¼	1	Nondrying	2.5	15	106	10.8
6F	Water-repellent preservative	------	75	89	1¼	2	Nondrying	15.0	22	103	[3] 21.6
7R	Water-repellent preservative	------	71	------	1⅜	2	Nondrying	1.3	28	100	[3] 25.0
8C	Water-repellent preservative	------	71	------	2¼	1	Nondrying	7.0	20	112	[3] 17.9
9P	Water-repellent preservative	------	70	------	1¾	1	Nondrying	3.0	26	92	[3] 17.1
12K	Water-repellent preservative	------	69	76	1¼	2	Nondrying	1.0	22	100	[3] 18.7
15A	Water-repellent preservative	------	65	71	2¼	3	Slow drying	4.0	17	112	[3] 15.5
18H	Water-repellent preservative	------	64	74	2¼	2	Nondrying	8.0	14	105	[3] 11.3
21K	Water-repellent preservative	------	62	81	1¼	2	Nondrying	0.7	24	104	[3] 16.0
23N	Water-repellent preservative	------	61		2	2	Slow drying	8.0	18	102	[3] 15.2
27P	Water repellent	------	59	------	1½	1	Nondrying	1.5	19	99	13.7
X2	Raw linseed oil, undiluted	3	50	------	------	------	------	------	------	------	------
	Commercial sealers and preservative sealers:										
34O	Sealer	------	35	40	⅛	10	Fast drying	0	2,310	------	19.0
39Q	Preservative sealer	------	16	76	⅛	8	Fast drying	0	670	75	[3] 44.7
41Q	Preservative sealer (lacquer)	------	12	------	3/16	8	Fast drying	0	126	[4] 30	[3] 20.7
43M	Sealer	------	10	62	⅛	7	Fast drying	0	291	75	26.1
46D	Sealer	------	5	61	⅛	5	Fast drying	0	100	43	19.6
52R	Preservative sealer	------	4	19	⅛	2	Slow drying	0	31	105	[3] 15.0
54F	Preservative sealer	------	2	30	⅛	7	Fast drying	0	41	94	[3] 24.2

[1] The units are scale readings of a reflectometer measuring the gloss of a semigloss enamel applied on wood previously treated with water repellent or sealer. Nos. 1, 2, 3 represent practically no gloss, indicating that much liquid from the enamel was absorbed by the treated wood. No. 10 represents nearly the full gloss of the enamel from which no liquid has been lost by absorption by the treated wood.

[2] Milliliters of precipitate, presumably wax, when 30 milliliters of acetone are added to 10 milliliters of water repellent or sealer and the mixture cooled to 35° F. for 1 hour and then centrifuged.

[3] Part of the nonvolatile, not exceeding 5 percent by weight based on total sample, was chlorinated phenol present as fungicide.

[4] Actual flash point less than 30° F.

form hard coatings on nonabsorptive surfaces such as tin plate, they penetrate less than one-fourth inch into end-grain sapwood and only a few fiber diameters into side-grain wood, and they seal the surface of wood against entrance of liquid from paint or varnish applied subsequently, that is, they "hold out" subsequent coatings and in that sense "prime" wood for further coating. Well-sealed wood takes on a deeper color and a degree of luster affording an attractive, "finished" appearance. The water repellency imparted to wood by a single application of sealer, by dipping or otherwise, is low, less than that obtainable by dipping in undiluted linseed oil. A second application of the better sealers after the first has dried, however, greatly improves the water repellency.

7.211. Water Repellents.—Commercial water repellents are usually of secret composition. The data of table 7–2 indicate that they usually contain even less nonvolatile than sealers, 10 to 25 percent by weight, the solvent is commonly mineral spirits with a flash point near or above 100° F., they are less viscous than sealers, they are nondrying or slow-drying on nonabsorptive surfaces, they penetrate an inch or more into end-grain sapwood but only a small fraction of an inch into side-grain wood, and they have practically no holdout for subsequent coatings. Treatment of wood with water repellent does not alter the appearance of the wood appreciably unless the water repellent contains colored ingredients. One application of water repellent by dipping imparts as much water repellency to wood as is obtainable with two applications of sealer, but a second application of water repellent further improves the water repellency only slightly.

All of the acceptable water repellents contain an ingredient that is precipitated by cold acetone. The sealers seldom if ever yield a precipitate in cold acetone. The nature of the acetone-insoluble ingredient in the commercial water repellent has not been identified by the Forest Products Laboratory. All of the properties of the commercial water repellents reported in table 7–2, however, can be matched closely with solutions of paraffin wax, which is insoluble in cold acetone, and resin in suitable proportions in mineral spirits. The Forest Products Laboratory has not been able to consistently obtain 60 to 80 percent water repellency in a single

application without incorporating some wax in the water repellent. Wax, however, tends to retard the drying or to impair the adhesion of finishing materials applied subsequently. Nevertheless resin, together with the penetrating property of water repellents, minimizes the interference between wax and finishes to such a degree that wood treated with satisfactory water repellents and allowed to dry until the solvent evaporates can be finished with the materials commonly used for house painting without significant retardation of drying or impairment of durability. Some of the water-repellent preservatives listed in table 7–2 have been widely used for nearly a decade on window sash and other millwork without causing difficulties with paints or other finishes.

Paints differ, however, in sensitiveness to wax. The relatively slow-drying products commonly used for the exterior and interior woodwork of houses are less sensitive than the fast-drying products usually preferred when finishes are applied at the factory. The attempt to apply water repellent and to follow promptly with painting on a production line is likely to give rise to difficulties with retarded drying. There is less danger if wood parts are treated with water repellent before shipment to the assembly plant or if they are treated well in advance of painting. Even so, however, if paints or finishes are to be applied in a closely timed production schedule care must be exercised to select suitable finishes that will dry promptly on treated wood.

Water-repellent preservatives contain fungicide in addition to water-repellent ingredients. Use of such products for preventing decay and blue stain is discussed in section 6.203. Preservative sealers likewise contain fungicide.

7.3. WOOD PROPERTIES THAT AFFECT PAINTING.—The durability of pain on exterior woodwork varies according to the properties of the wood (*7–2*). As a rule woods hold paint longer the lower their density, though other properties are also important. Among softwoods the width of the bands of summerwood is a dominant consideration. Low density corresponds to a low proportion and narrower bands of summerwood, but even at the same density the summerwood bands are narrower and paint retention better in slowly grown wood, with many growth rings per inch of log radius, than in rapidly grown wood. Edge-grain boards or face veneers in plywood have narrower bands of summerwood and hold paint better than flat-grain boards or rotary-cut face veneers in plywood.

The more important species of wood are classified in five groups in decreasing order of preference of the group for exterior painting, as follows:

Group 1.—The cedars, baldcypress, redwood (softwoods).

Group 2.—Eastern white pine, Western white pine, sugar pine (softwoods).

Group 3.—True firs, hemlocks, spruces, and the yellow pines of lower density, such as ponderosa pine (softwoods); aspen, basswood, cottonwood, magnolia, and yellow-poplar (hardwoods).

Group 4.—Douglas-fir, Western larch, tamarack, and southern yellow pine (softwoods); and birch, sweetgum, black tupelo, and maple (hardwoods).

Group 5.—Ash, chestnut, elm, mahogany, oaks, and walnut (hardwoods with large pores requiring use of wood filler).

For interior surfaces to be painted or enameled, the same classification applies with respect to the softwoods. Although interior paints seldom deteriorate to the point of flaking from summerwood bands, wide bands of summerwood tend to show as raised grain under enamel finishes or require more work to smooth the surface sufficiently for the best appearance of enamel. For natural finish, wide summerwood presents an unduly coarse grain pattern, which is accentuated if wood stain is used. For interior surfaces the hardwoods of groups III and IV are superior to the softwoods of group I. The hardwoods of group V require filler for smooth varnish or enamel finishes, but for finishes of the sealer type filler may be omitted. For natural and stained finishes, most hardwoods present more pleasing gradations in color and grain than the softwoods. In selecting wood for interior uses selection for finishing properties must often be subordinated to selection for such mechanical properties as hardness and resistance to wear.

High grades of lumber are superior to grades containing knots, pitch pockets, or excessive pitch for all exterior painting and for most interior painting. The defects either require extra operations in finishing or lead to early

blemishes of one kind or another in the painting. Often the blemishes appear despite the extra precautions in painting. If knotty lumber must be used on exterior surfaces, it is not worthwhile to shellac the knots before painting because it may cause alligatoring and hasten failure of the coating over the knots. On interior woodwork knots may be shellacked before painting or after the priming paint has been applied to prevent discoloration or loss of gloss of the paint. Knotty lumber is sometimes used for natural or stained interior woodwork when the knots are considered decorative.

Woodwork that has become damp from proximity to fresh plaster or other sources of moisture should be allowed to dry again thoroughly before it is painted to avoid danger of blistering, discoloration by blue stain in sapwood, or yellow discoloration over heartwood of pine lumber.

7.4. KINDS OF PAINT USED FOR HOUSES.—The paints and other finishes of established reputation for housing have been developed for the painting methods suitable for application and subsequent maintenance at the building site. Site painting is done principally by hand brushing under conditions that make fast-drying paints unnecessary and often inconvenient. The labor commonly costs at least 4 or 5 times the cost of the paint used. For prefabricated housing, painting at the factory offers the attractive possibility of great reduction in labor by mechanization but presents two serious problems: (1) That of transporting and erecting painted units without soiling or marring coatings seriously; and (2) that of providing for drying of coatings without excessive floor space and delay in production. A practical compromise with the first problem is to apply all but finish coats at the factory, applying the finish coats after erection at the site. The second problem can be dealt with by selecting fast-drying finishes for those surfaces for which they are available and by using systems of forced drying to speed the drying of finishes. As yet, however, the fast-drying finishes suitable for woodwork in housing are severely limited, particularly when consideration is given to the need for maintaining them with the kinds of paints suitable for painting at the site. For exterior woodwork, there are no truly fast-drying paints that are known to be compatible with ordinary house paints.

7.40. Paints for Exterior Woodwork.—There are no recognized commercial standards for house paints. Agencies of the Federal Government normally order paint under specifications of the Federal Specifications Board (*7–7*), a practice that can be recommended to prefabricators or others whose purchases are large enough to justify establishing or retaining a testing laboratory to see that deliveries conform to specification. It is inadvisable for paint buyers to prescribe paint specifications of their own unless the specifications can be drawn by one skilled in the exacting requirements of the subject. Much paint is purchased by trade brand, in which case the paint maker has freedom to set or to alter the composition. It is generally customary for the maker to reveal the formula reasonably completely, except that the composition of varnishes and varnish vehicles is disclosed only partially as a rule. Since house paints differ characteristically in performance according to their composition, the user of paint often wishes to exercise his choice in the matter. To that end the United States Department of Agriculture has proposed a system of classification of house paints according to composition (*7–3*).

Paints are classified under this system by group, type, and grade. The group depends on the principal pigments and the kind of vehicle, which govern the behavior of the paint in service. For house paints in white and light colors, the principal pigments are white lead, represented by the letter *L*, zinc oxide, *Z*, titanium dioxide, *T*, and zinc sulfide, *S*. Paint made with white lead, zinc oxide, and titanium dioxide in ordinary linseed oil, for example, belongs to group *TLZ;* if a substantial portion of the oil has been bodied, that is, thickened by heating as in the wartime oil-restricted paints, the group is *TLZ*(*e*). An enamel made with titanium dioxide and varnish belongs to group *T*(*re*). In strongly colored paints the principal pigments are iron oxide, *F*, lead chromate, *L*, or other colored pigments, *C*. The paint type depends upon the proportions of chemically active pigments, *L* and *Z*, which are particularly important in governing the behavior of paints made with linseed oil. Type 1A means very high con-

tent of L and Z with much more L than Z, type 3B means medium content of L and Z with more L than Z, type 3C medium content of L and Z with more Z than L, and type 5 very low content or absence of L and Z. Paints are assigned to one of 6 grades according to rules based on the content of total pigment, opaque pigment, and total nonvolatile matter. House paint finish coat of grade 1, for example, must contain not less than 0.25 gallon of total pigments, opaque pigments equivalent to not less than 0.25 gallon of white lead, and not less than 0.87 gallon of nonvolatile ingredients in a gallon of prepared paint. For further details reference (*7–3*) should be consulted.

7.400. Priming Paints for Wood.—The first coat of paint applied on bare wood undergoes serious change in composition because a substantial proportion, one-half or even more, of the liquid portion of the paint penetrates into the wood while the pigments are left on the surface. As a result, the coating left on the surface contains a disproportionately low content of oil vehicle; it dries without gloss, has little moisture-excluding effectiveness, and chalks away rapidly if left exposed to the weather very long. The older practice in painting was to add extra linseed oil to paint for priming to compensate in part for the oil absorbed by the wood. Such self-priming, however, tended to defeat itself by decreasing the amount of pigment and increasing the spreading rate to a point at which the primer neither accomplished its first purpose of satisfying the absorption of liquid by the wood nor contributed to building the required thickness of coating.

Modern house-paint primers were designed to fully satisfy the absorption of liquid by wood and at the same time to contribute materially to building the required thickness of coating. They became the basis of the "two-coat painting system" (*7–4*) in which new woodwork is durably painted with one coat of primer and one coat of finish paint in place of the three coats necessary with self-priming. The saving in labor is important in site painting but may be less urgent in mechanized factory painting. House-paint primer, sometimes called controlled-penetration primer, usually contains as much pigment as finish paint, but the vehicle contains a large proportion of linseed oil that has been bodied with or without a small addition of resin. Bodied oil penetrates wood less deeply and is less easily drawn away from pigments than raw oil. Such primers have a consistency that permits application in the thick coat necessary for two-coat painting. In addition, they have been found to make longer-lasting paint jobs than the old self-priming procedure.

The house-paint primers are predominantly of group TL, type 4A. A representative composition for grade 1 primer is:

	Gallon
White lead	0.065
Titanium dioxide	.044
Extending pigment	.151
Raw linseed oil	.235
Bodied linseed oil	.235
Mineral spirits and drier	.270

The opaque pigments are equivalent in opacity to 0.25 gallon of white lead, the total pigment is 0.26 gallon, and the total nonvolatile is 0.73 gallon. The white lead may be basic carbonate white lead, basic sulfate white lead, or a mixture of the two. The titanium dioxide may be pure pigment, or the titanium dioxide and most of the extending pigment may be supplied in the form of a composite pigment, titanium-magnesium, titanium-barium, or titanium-calcium. The extending pigment is usually magnesium silicate or barium sulfate, but other inexpensive pigments of low opacity may be used instead. The bodied linseed oil may be party tung oil and may have a small portion of resin if desired. The formula by weight, as usually reported, is approximately 61 percent pigment and 39 percent vehicle, and the pigment is 42.5 percent white lead, 16.5 percent titanium dioxide, and 41 percent magnesium silicate; or, if the extending pigment is barium sulfate, 6 percent pigment and 34 percent vehicle, with the pigment consisting of 34.5 percent white lead, 13.5 percent titanium dioxide, and 52 percent barium sulfate. In either case, the vehicle is about one-third each of raw linseed oil, bodied linseed oil, and mineral spirits.

Aluminum house paint makes an excellent priming paint, especially for the softwoods in groups III and IV, section 7.3 (*7–4, 7–5*). It improves the durability of coatings by delaying early flaking from wide bands of summerwood. Aluminum paint also stands handling well because it is relatively resistant to scratching or gouging in handling and is easily patched if it does become marred. When a priming paint is

required to furnish protection against change in moisture content during transportation and storage before erection, aluminum primary paint affords about as much protection as can be obtained with a single application. One coat of aluminum primer followed by one of house-paint primer or of house paint assures good protection pending the application of the last coat after erection at the site. Aluminum house paint consists of 1¾ to 2 pounds of paste aluminum (about 65 percent by weight in mineral spirits) in 1 gallon of vehicle. The vehicle is a varnish made specifically for the purpose; it has more drying oil and less resin than spar varnish, in the terminology of varnish making it is an 80-gallon varnish, and it should contain not less than 55 percent by weight nonvolatile. Aluminum paints made for other purposes, as for painting of metal, are unsuitable for priming of wood.

Neither house-paint primer nor aluminum primer is fast-drying. At the present time there are no fast-drying paints that can be recommended for priming exterior woodwork that is subsequently to be painted with house paints. Until recently there has been little incentive for the development of such products. Although there is reason to believe that fast-drying primers thoroughly compatible with house paints for site application are possible, much time will necessarily be required to establish their merits.

Water repellents and wood sealers must not be regarded as substitutes for priming paint. If they are used to provide a limited degree of temporary protection, as indicated in section 7.21, it should be understood that the painting at the site should begin with a priming coat just as it does with bare wood. On wood treated with water repellent, the primer must satisfy the absorption of the wood and contribute to the building of a coating. Wood treated with a good sealer is largely satisfied in absorption, making the controlled-penetration feature of the primer less important, but it still needs the primer's contribution to the building of a coating. Excessive amount of wood sealer or varnish before painting should be avoided, because it may cause early failure of paint coatings by alligatoring (*7–5*).

7.401. Paints for Finish Coat.—House paints of grade 1 in the United States Department of Agriculture classification are made with unbodied linseed oil. They contain at least 0.25 gallon of equivalent opaque pigment, 0.25 gallon of total pigment, and 0.62 gallon of linseed oil and not more than 0.13 gallon of thinner and drier in a gallon of paint when ready for application. One gallon of such oil-rich paint contains 201 cubic inches of nonvolatile ingredients, pigments plus linseed oil, which suffices to cover 558 square feet of smooth surface with a coating 2.5 mils thick. Because of the scarcity of fats and oils at the present time, oil-restricted paints have largely replaced oil-rich paints. In oil-restricted paints there is usually about 0.50 instead of 0.62 gallon of linseed oil, but part of the oil, say 0.20 to 0.25 gallon, is bodied and the rest unbodied linseed oil. There is, of course, nearly twice as much volatile thinner—that is, 0.25 instead of 0.13 gallon—in the oil-restricted as in the oil-rich paint. One gallon of oil-restricted paint contains about 173 cubic inches of nonvolatile ingredients, which suffices to cover only 481 square feet of smooth surface with a coating 2.5 mils thick. The oil-restricted paints are therefore less economical for the user because they cover less surface adequately or, conversely, take more paint and labor to cover adequately a fixed area of surface than the oil-rich paints do. Once they have been applied, however, the oil-rich and oil-restricted paints perform similarly.

Resins are seldom used in the vehicle of finish-coat paint, except in paints of dark color discussed farther on, largely because the incorporation of resin with drying oil produces a highly bodied vehicle to which much thinner must be added. The product usually becomes an enamel rather than a paint. A typical enamel might contain 0.20 gallon of total pigment and 0.35 gallon of resin and drying oil per gallon of enamel. There would then be only 127 cubic inches of nonvolatile in a gallon of the enamel; to obtain 2.5 mils of coating thickness, it would be necessary to apply two coats, each one at 700 square feet per gallon. For that and other technical reasons the new resins developed in recent years have not led to new kinds of house paints despite the appearance of miscalled "plastic paints" on the market and publicity in certain "popular" publications (*7–8*).

Commercial house paints vary greatly in pigment, composition, and in those characteristics

of performance that are determined by the pigments. The varieties most widely available as paints of high grade usually fall in one of the three following classifications: group *L*, type 1A; group *TLZ*, type 3B; or group *TLZ*, type 4C.

7.4010. Group L Type 1A Paints.—The pigment used in paints of group *L*, type 1A consists entirely of white lead, usually basic carbonate white lead, except for small proportions of colored pigments when required for color. The formula by weight is: Pigment 71 percent, consisting of white lead 100 percent; and vehicle 29 percent, consisting of linseed oil 85 percent, thinner and drier 15 percent. In its oil-restricted form the paint is group *L(e)*, type 1A, and the formula is: Pigment 72 percent, consisting of white lead 100 percent; and vehicle 28 percent, consisting of raw and bodied linseed oil 70 percent, thinner and drier 30 percent.

Paint of group *L*, type 1A is distinguished for its reliable service under the great variety of conditions met in practice and for the ease and economy with which it can be maintained even when unduly long intervals are allowed to elapse between paintings. It serves particularly well on the softwoods in groups III and IV, section 7.3. These favorable qualities result from the development of a fine pattern of paint checking a year or two after the paint has been applied. The checking forestalls more serious cracking, curling, and flaking that eventually occur with other paints and brings about an ultimate breakdown by fine crumbling, which leaves a surface that is easy to repaint without laborious preparation. On the other hand, paint of group *L*, type 1A, becomes more seriously soiled with dirt and in warm, damp climates is more likely to become discolored by mildew than some other paints. In brief, paint of group *L*, type 1A, is likely to prove less attractive during the first year or two after application but more reliable and economical in the long run than most other paints.

7.4011. Group TLZ Type 3B Paints.—The pigment of group *TLZ*, type 3B paint consists of a medium proportion of white lead, a slightly lower proportion of zinc oxide, enough titanium dioxide to give good opacity, and a substantial proportion of inexpensive extending pigment. A representative formula by weight is: Pigment 62 percent, consisting of white lead 36 percent, zinc oxide 25 percent, titanium dioxide 12 percent, and magnesium silicate 27 percent; and vehicle 38 percent, consisting of linseed oil 85 percent, thinner and drier 15 percent. In the oil-restricted modification, group *TLZ(e)*, type 3B, the pigment is 63 percent by weight and the vehicle 37 percent consisting of raw and bodied linseed oil 70 percent, thinner and drier 30 percent.

Paint of group *TLZ*, type 3B, usually stays cleaner and resists mildew better during the first year or two after application than paint of group *L*, type 1A. Checking does not develop rapidly enough to forestall cracking, curling, and flaking of such *TLZ* paints. For that reason greater care in conforming to the best painting practices and in repainting before the coating breaks down too badly is needed to avoid expensive preparation of the surface before repainting than is the case with paint of group *L*, type 1A. For white paints of group *TLZ*, type 3B, the titanium dioxide should be of a freely chalking kind, which helps maintain a clean surface, relatively free from dirt. For colors, however, the freely chalking titanium dioxide causes serious fading of colors which can be minimized by using a chalk-resistant kind of titanium dioxide. For that reason colored paint should not be made by tinting a white *TLZ* paint on the job. If the user wishes to have the painter make tints on the job, it is usually possible to buy a "white base for tinting," which contains chalk-resistant titanium dioxide but the white base for tinting, in turn, should not be used for white paint.

7.4012. Group TLZ Type 4C Paints.—The pigment used in group *TLZ*, type 4C paint consists of a medium proportion of zinc oxide, a low proportion of basic sulfate white lead, enough titanium dioxide to give good opacity, and a substantial proportion of extending pigment. A representative formula by weight is: Pigment 60 percent, consisting of white lead 17 percent, zinc oxide 33 percent, titanium dioxide 15 percent, magnesium silicate 35 percent; and vehicle 40 percent, consisting of raw and bodied linseed oil 85 percent and thinner and drier 15 percent. In the oil-restricted form, group *TLZ(e)*, type 4C, the pigment is 61 percent by weight and the vehicle 39 percent, consisting of raw and bodied linseed oil 70 percent, thinner and drier 30 percent.

Paint of group *TLZ*, type 4C, stays relatively clean and resists mildew well but does not hold tints so well as *TLZ* paint of type 3B. For tinted *TLZ* paints of type 4C it is imperative that chalk-resisting titanium dioxide be used, although freely chalking titanium dioxide is generally used for white paint. Paints of group *TLZ*, type 4C, usually remain entirely free from checking and under favorable conditions may remain free from cracking until they have wasted away by chalking to a point requiring repainting. Under less favorable conditions, however, cracking is inclined to develop in a conspicuous pattern that leads to scaling and a difficult and uncertain condition for repainting. The type 4C paints are relatively new products for which some further years of practical experience will be needed to determine fully their advantages and limitations.

Paints of type 4C are sometimes made with zinc sulfide instead of titanium dioxide for the principal opaque pigment. Such paints, which are group *SLZ*, type 4C, hold color better but may not stay quite so clean or so free from checking as the *TLZ* paints of that type. The *SLZ* paints are less highly regarded than the *TLZ* paints, perhaps in part because of prejudice from the fact that zinc sulfide has long been widely used in paints of inferior grade.

Deeply colored paints that cannot be made by tinting white paint are usually unsuitable for the principal areas of small houses but may be required for shutters, trim, or other small areas on which contrast in color is desired. For a number of technical reasons it is difficult to make such paints satisfactorily with a linseed oil vehicle. Instead, it has become customary to use enamels for "trim and trellis" colors. Enamels made with long-oil, alkyl-resin varnishes have been particularly successful because they hold their gloss and color for a long time, properties that are especially desirable in the deeply colored coatings. If the wood is first primed with house-paint primer, the thin finish coat obtained with such enamels has adequate opacity and durability for the purpose.

7.41. Paints for Interior Woodwork.—Since interior paints are not exposed to the rigors of the weather, they usually last until the desire for a change in decorative scheme or soiling of the surfaces leads to their renewal. Details of composition of interior paints are therefore of less interest to users than are such matters as convenient working properties and the desired appearance. Such characteristics can usually be determined satisfactorily by rapid tests in a laboratory or by trial of samples in a workshop.

7.410. Transparent Finishes.—The wood sealers, described in section 7.210, are the simplest kind of transparent finish. Such finishes have become increasingly popular during the past decade. They are particularly suitable for factory application because they require a minimum number of coating operations, dry very rapidly, and stand subsequent handling and shipment with relatively little danger of being scratched or otherwise marred. Minor blemishes are easily repaired after erection at the site.

Wood sealer is usually so light in color as to be essentially colorless when spread in a thin layer. Nevertheless its application seems to darken the color of wood. Actually it brings out the natural color of the wood more intensely by displacing air in the wood cavities with resin and oil of much higher refractive index for light. Rays of light penetrate farther into the wood and take on more of the wood's color before they are reflected back to the observer's eyes. Wetting wood with water has much the same effect until the water evaporates again.

When so desired, the color of the wood may be altered by applying wood stain before the wood sealer or by incorporating oil stain in the wood sealer. Care must be taken in staining softwoods, however, because the springwood takes up more stain and becomes darker than the summerwood with results that some consider displeasingly unnatural. Natural finish of color lighter than that of the wood can be obtained as follows: Thin white enamel undercoater with an equal volume of mineral spirits; spread the mixture thinly over the wood surface; before it has time to dry, wipe off what remains on the surface with cotton waste, burlap, or clean rags; then let dry and apply wood sealer. Variations in color can be obtained by tinting the undercoater slightly with colors-in-oil or by applying a pigment oil stain after the white undercoater, following the same method.

On hardwoods with irregular grain, light staining often serves to bring out attractive variations that without staining may be less noticeable. Hardwoods with pores larger than those in birch may be left with the pores open

before wood sealer is applied; or wood filler of dark color, which accentuates the pattern of the pores, may be applied before the wood sealer. In hardwoods with pores smaller than those in birch, wood filler adds little to appearance because so little of it penetrates the wood.

More lustrous transparent finishes are obtained by applying several coats of varnish until the wood surface has been covered with a layer 1 to 3 mils thick. As pointed out in section 7.20, varnish finishes provide greater protection for wood than is obtained with wood sealer. The appearance is different but choice between them on that score is a matter of individual preference. As with wood seal finishes, varnish finishes may be varied by use or omission of wood stain beforehand. On hardwoods with pores larger than those in birch, however, wood filler is necessary before varnishing; if it is desired not to accentuate the pore pattern of the wood, natural wood filler, that is, filler made with transparent pigments only, may be used.

Varnish may be either highly glossy or dull. As a rule dull varnish is preferred for large areas of woodwork, such as wood paneling; glossy varnish may be suitable for wood trim, floors, and furniture.

For factory application, clear lacquer may be used in place of varnish because it dries much more rapidly. Lacquer, however, contains only one-third to one-half as much nonvolatile as varnish. For that reason it takes two to three coats of lacquer to build as much coating thickness as is obtained with one coat of varnish. When stain or filler is applied, a suitable lacquer sealer may be necessary before applying clear lacquer.

Many woods with natural finish change in color as time passes, usually becoming darker in color. The change proceeds faster on those areas that receive most light, particularly sunlight. When pictures hung for some time on a wood-paneled wall are moved it may be found that the area under the picture is lighter in color than the surrounding area. Such change in color is due to the action of light on substances in the wood. No way of preventing the change in color is now known. Varnished woodwork may undergo further darkening in color because the varnish itself darkens with age. The old varnish, of course, may be removed and replaced with fresh varnish when the darkening goes too far.

7.411. Opaque Finishes.—Opaque finishes for interior woodwork should be enamels of the oleoresinous or of the lacquer type. Water paints and emulsion paints or enamels are not recommended because they are low in protective power and may raise the grain of the wood. Oleoresinous enamels are made of varnish in which enough pigment has been ground to provide adequate opacity and color. Lacquer enamels consist of pigments ground in cellulose ester lacquers.

Interior paints or enamels are of three different degrees of luster, high gloss, semigloss, and flat (lusterless). The enamels of high gloss may be divided further into true enamels intended to produce a surface of mirrorlike smoothness and enamelized paints intended to spread more easily, to go on in thicker coatings, and to leave a surface of distinctly less than mirrorlike smoothness. The usual differences in composition are illustrated by the data of table 7–3, though considerable latitude from the given figures is permissible. Lacquer enamels rarely, if ever, contain more than half as much total pigment and total nonvolatile as indicated in the table.

Titanium dioxide or zinc sulfide is usually the principal opaque pigment in white or light-colored enamels, though some manufacturers

Table 7–3.—*Representative composition of different kinds of oleoresinous enamels*

Item of composition	Flat enamel or paint	Semigloss enamel or paint	Gloss enamelized paint	Gloss true enamel
	Gal./gal. of enamel	*Gal./gal. of enamel*	*Gal./gal. of enamel*	*Gal./gal. of enamel*
Equivalent opaque pigment	0.23	0.25	0.30	0.35
Total pigment	.30	.24	.22	.10
Total nonvolatile (pigment plus nonvolatile vehicle)	.50	.60	.75	.60
Ratio of total pigment to total nonvolatile	.60	.40	.30	.15
Volatile thinner	.50	.40	.25	.40

include a small proportion of zinc oxide. The true enamels contain little or no pigment of low opacity; the enamelized paints and semigloss enamels contain substantial proportions, and the flat paints large proportions of pigments of low opacity.

The enamels are designed for use as finish coats. Flat paint serves reasonably well for priming bare wood; semigloss and gloss paints usually make poor primers, and true enamels are entirely unsuitable for priming wood. For that reason, enamel undercoaters are made for use on wood before applying interior paint or enamel. Undercoaters have approximately the same composition as that given for flat paint in table 7–3, but the pigments and varnish are selected to ensure good priming characteristics and ease of sanding after the undercoater has dried.

True enamel should be used only when it is considered worthwhile to prepare the woodwork with perfectly smooth surfaces, which usually requires careful sanding just before coating, application of at least two coats of undercoater, and sanding of the surface after the second application of undercoater. Unless a really smooth surface is obtained, gloss enamel will accentuate the imperfections in the surface. Planer marks or raised grain on wood, for example, may be practically invisible before finishing and yet appear conspicuously after applying gloss enamel without proper preparation and undercoating. If gloss finish at lower cost is required, or if the wood has blemishes that cannot be removed, a more attractive result will be obtained with undercoater and gloss enamelized paint, selecting products that leave slight brush marks or, if applied by spraying, slight pimpling of the kind usually called "orange peel."

As a rule, high gloss is considered suitable for relatively small areas that are to be accentuated, such as trim or moldings. On large areas, the specular reflection of light from highly glossy surfaces is uncomfortably harsh. On the other hand, gloss paints furnish greater moisture-excluding effectiveness and stand more washing to keep them clean than is the case with flat paints. Semigloss enamels afford a suitable compromise between the extremes; they scatter reflected light enough to be attractive in appearance even on large areas, yet they stand washing well and furnish good protection.

For large areas, flat paints usually provide the best appearance. In addition they are much less inclined to render blemishes, dents, wood checks, or raised grain conspicuous than is the case with gloss or semigloss paints. Flat paints become soiled with dirt less rapidly than gloss paints. On the other hand, stains of a liquid or greasy nature and perspiration from hands penetrate deeply into flat paints and can seldom be removed satisfactorily by washing. Trim and other parts of wood likely to be handled frequently are therefore best finished with semigloss or gloss paints.

There is another type of flat paint available, designed for large areas such as wall and ceiling panels, made of wood containing blemishes or likely to develop checking. This type of flat paint presents a rough surface of attractive appearance which serves to distract attention from the blemishes in the underlying surface. The roughness comes from coarsely granular pigments incorporated in the paint. Still another method is to make a stippling paint, the consistency of which is such that, after it has been spread and is still wet, it can be tapped with a stippling brush to produce a pattern of pimples on the surface.

7.5. PAINTING SYSTEMS.—The following painting systems are suggested as typical of satisfactory finishes for the surfaces indicated:

7.50. Exterior Surfaces.—Woodwork with rough surfaces, such as the split or sawed surfaces of shingles, may be left to weather naturally without protection or may be decorated with shingle stain. Shingles are best stained by dipping to at least two-thirds their length before they are laid so that both sides of each shingle receive stain. Shingles may be purchased already stained by the manufacturer. Painting is not considered suitable for shingle roofs but is an acceptable procedure for shingle side walls. Two coats of house paint may be used for that purpose. The first coat should be applied by dipping before the shingles are laid; the second is best applied by spraying but may also be applied by brushing after laying the shingles.

7.501. Side Walls.—Natural finish, such as linseed oil, wood sealer, or varnish with or without wood stain, is not considered a good choice for smooth woodwork fully exposed to the weather, although there has been a vogue for such finish in recent years. The natural finishes

are inclined to become grimy from mildew and, if not renewed at least once a year, the wood tends to become gray from weathering. When grayed, the surface must be scraped or sandpapered before renewing natural finish. If natural finish is insisted upon, it is recommended that the wood be treated with water-repellent preservative (sec. 7.211) or NSP preservative (sec. 6.202) before applying wood sealer or varnish. Front doors that are reasonably sheltered by porch roofs, however, may be given a natural finish when desired. Treatment with water-repellent or NSP preservative followed by three or more coats of spar varnish is advisable.

Coatings of paint on smooth side walls should be 4.5 to 5.0 mils in thickness when the last coat has dried in order to provide satisfactory durability, which normally is expected to be 4 to 5 years. Modern paints will often hide the underlying surface when only 2.0 mils thick, hence more than enough paint merely to hide the surface is required. Using house-paint primer and oil-rich house paint of the kinds discussed in section 7.40, the requisite thickness of coating can be obtained with two coats of paint by applying the primer at the rate of 450 square feet to the gallon and the finish paint at 550 square feet per gallon. If oil-restricted paint must be used for the finish coat, the spreading rate must be reduced to a point that is likely to prove impracticable.

When oil-restricted paint must be used or when painting is done at the site during cold weather, a three-coat system is advisable. The three-coat system may also prove a better choice for factory painting where mechanization makes the labor cost low and the faster drying of thin coats of paint proves more important. For three-coat work, the house-paint primer should be applied at 600 square feet to the gallon, followed by two coats of oil-rich house paint each at 700, or two coats of oil-restricted house paint at 600 square feet to the gallon. When woods of groups III or IV in section 7.3 are being painted in three-coat work, aluminum house paint applied at 700 square feet to the gallon is advisable for the first coat.

7.502. Trim, Sash, and Doors.—Window sash and exterior doors made of woods that contain much sapwood or other wood of low resistance to decay may well be treated with NSP preservative or water-repellent preservative. Those items of exterior trim, such as handrails, palings, porch columns, and vertical members resting on sills, which leave joints likely to admit rain water to end-grain wood, may well be similarly treated. The treating should be done before erection.

When trim, sash, and doors are to be painted in white or light color, the painting system should be one of those suggested for side walls of smooth wood. When trim paint of a deep color is desired, it is advisable to follow a three-coat system. For the first coat apply house-paint primer at 450 square feet to the gallon; for the second coat tint house-paint primer dark gray or buff and apply at 600 square feet to the gallon; apply the trim paint at 800 square feet to the gallon. Green trim paint looks best over a gray undercoat, dark brown looks best over a buff undercoat.

7.503. Porch Floors.—Porch flooring may well be treated with NSP preservative or water-repellent preservative before it is laid.

The paint for porch floors must be hard enough to stand traffic yet tough enough to stand weather. Porch and deck paints for the purpose are types of enamelized paint (table 7–3) in which the varnish is of a kind suitable for exterior use. The painting system suggested consists of house-paint primer applied at 600 square feet to the gallon, followed by two coats of porch and deck enamel each applied at 600 square feet to the gallon.

7.51. Interior Surfaces.—In painting interior surfaces, the thickness of coating is relatively unimportant provided that enough paint is applied to produce the desired appearance. When minimum cost is an important consideration, the simpler finishes will be selected and standards of appearance may be somewhat lower than for more expensive houses.

7.510. Walls and Ceilings.—Plywood walls and ceilings may be finished in one of the natural finishes described in paragraph 7.410. Finishes that end with wood sealer or dull varnish are advisable because gloss varnish produces too much glare for large areas. Joints between panels necessarily remain visible with natural finish; they must be designed to produce acceptable appearance. Face veneers on plywood for natural finish should be free from patches or other blemishes. The grain pattern for the

different panels in any one room should be reasonably uniform, or else the panels should be arranged to present a pleasing ensemble. These requirements present difficulties in mass production that may offset the advantages of the natural finishes, namely, simplicity, fast drying, and the fact that a moderate degree of wood checking remains inconspicuous. Moreover, the natural finishes probably do not enjoy so wide an acceptance for small rooms as the opaque finishes or wallpaper.

For minimum cost, opaque finishes may consist of one coat of undercoater and one of flat wall paint. If desired, the flat paint may be one of rough texture. In bathrooms and kitchens, however, semigloss enamel may be preferred because it will stand more washing. It is difficult to conceal joints between panels. When acceptable, the easiest procedure is to design joints that will fit into the decorative scheme and let them show. Light, butt-glued joints may be concealed by new paint but the paint usually cracks over the joint within a short time. If the joint itself is firm enough despite seasonal changes in moisture content, it can be concealed reasonably well by routing out the face veneers along the joint just enough to take a fabric tape and then smoothing the depression with knifing putty before painting. The best method, if costs permit, is to cover the entire wall or ceiling with cloth and then paint or wallpaper over the cloth.

7.511. Trim.—Natural finishes of either the wood-sealer or varnish type are suitable for trim. If opaque finish is selected, the minimum system is one coat of undercoater and one of semigloss or gloss enamel. Flat paint is seldom to be recommended for trim because of the ease with which flat paint is soiled by grime and perspiration from hands.

7.512. Floors.—For application at the factory, the wood seal finish is undoubtedly the best choice, both because of the speed with which it can be applied and the resistance to marring during shipment and installation. For application after installation at the site, the floor seal finish remains a suitable and popular choice, though floor varnish may be used instead if it is preferred.

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INSULATION AND VENTILATION OF HOUSES

8.0. GENERAL.—The various functions of the modern house as a home in which the occupants daily perform all the domestic activities incident to family life place upon it severe burdens. The primary function of shelter from the elements is far from the only service performed by the house. It serves as a place for eating, bathing, laundering, entertaining, and a hundred other activities.

All these functions must be given consideration not only in the design and installation of equipment but in the design and construction of the insulated elements of the house itself—the walls, floors, and ceilings. In prefabricated houses, especially those built of light-weight materials, the design problems incident to these functions are accentuated. Experience has proven conclusively that, in most parts of the United States, and for most construction systems, the addition of insulation is necessary to provide reasonable economy of fuel in winter and adequate comfort in the house in both summer and winter. Resistance to heat flow inherent in the construction, or addition of insulation, is therefore necessary. Problems of ventilation and condensation, particularly in tightly built houses that are well insulated, weatherstripped, and otherwise equipped to avoid heat loss, must be dealt with by the designer and builder. Otherwise the house will fail to perform its functions satisfactorily, and very probably its period of use will be seriously shortened.

8.1. INSULATION.

8.10. General.—In low-cost housing, it is necessary to take advantage of every possible economy of material and labor. These economies must not, however, be carried to the point where the comfort of the occupants is sacrificed and the cost of heating becomes excessive. Houses should be so constructed that they will be comfortably warm and free from drafts in cold weather and comparatively cool during hot weather. Since most building materials used for wall and ceiling construction have relatively low resistance to heat transmission, insulating materials should be added where necessary to increase the resistance to heat exchange (*8–9*).

Insulation is of particular importance in prefabricated construction consisting of standard parts made of thin outer and inner covering materials over a light framework. Without insulation, the heat transmission through such parts would be excessive. Moreover, some types of insulation contribute to the fire resistance of the insulated parts (sec. 6.320).

Human comfort exists within a narrow range of air temperatures and surrounding surface temperature conditions. It has been generally accepted that a proper air temperature for residences is 70° F., but no standard has been so far established for the surface temperatures of enclosing floors, walls, and ceilings. It is generally agreed, however, that the closer these surface temperatures are to 70° F., the greater is the degree of comfort, and that surface temperatures more than 10° F. lower than the air temperature are a prominent cause of discomfort. A standard for surface temperature of not less than 64° F. is suggested as one that is reasonable from the standpoint of comfort, and practical and economical from the standpoint of the availability of insulating materials. The tendency of modern design to use larger glass areas, which are usually responsible for cold drafts, requires that the physical discomfort for which they are responsible be offset as much as possible by limiting the heat transfer through other areas. Insulation is an effective, practical, and economical means of maintaining walls, ceilings, and floors within the comfort range and of lessening the discomfort caused by drafts generated by cold surfaces.

8.11. Insulation.

8.110. Relation of Climate to Insulation.—Enough insulation should be provided to assure comfort and economical heating in the coldest weather expected where the house will be erected (*8–2*). Because winter temperatures vary materially in different parts of the coun-

try, buildings in cold zones require more insulation than those where winters are less severe. Heating engineers recognize this principle in meeting heating requirements, and for design purposes (*8–1*) use outside design temperatures established for each major city or area. These temperatures are generally selected at 15° F. above the lowest recorded temperature for each location, or are based on the average minimum temperature for that location, or on established local practice. Actual design temperatures, particularly in the mountain areas, may differ locally as much as 20° F. from the design temperatures shown in figure 8–1, and local weather records should be examined to adjust them accordingly.

8.111. Insulation Requirements.—It is comparatively simple to determine the amount of insulation required to accomplish a desired result (*8–7*). The thermal properties of most building materials are known, and the coefficient of transmission, or U value, for most combinations of construction and insulation can be calculated. The U value represents the over-all coefficient of heat transmission and is the amount of heat expressed in British thermal units transmitted in 1 hour through 1 square foot of surface per 1° F. difference in temperature between the inside and outside air.

Figure 8–2 illustrates various wall, ceiling, and floor test panels typical of prefabricated construction with different amounts and types of insulation installed for comparative purposes. The U values for each combination of material are given in tables 8–1 through 8–3, together with the inside surface temperature calculated for each design-temperature zone shown in figure 8–1. By means of these values, it is possible to compare the insulating effectiveness of the constructions shown in figure 8–1.

The values for interior surface temperatures given in table 8–1 for ceiling panels shown in

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FIGURE 8–1.—Average minimum temperatures of the United States by zones, for use in designing for insulation requirements of houses. (*Map from 1947 ASH&VE Guide.*)

748308°—48——9

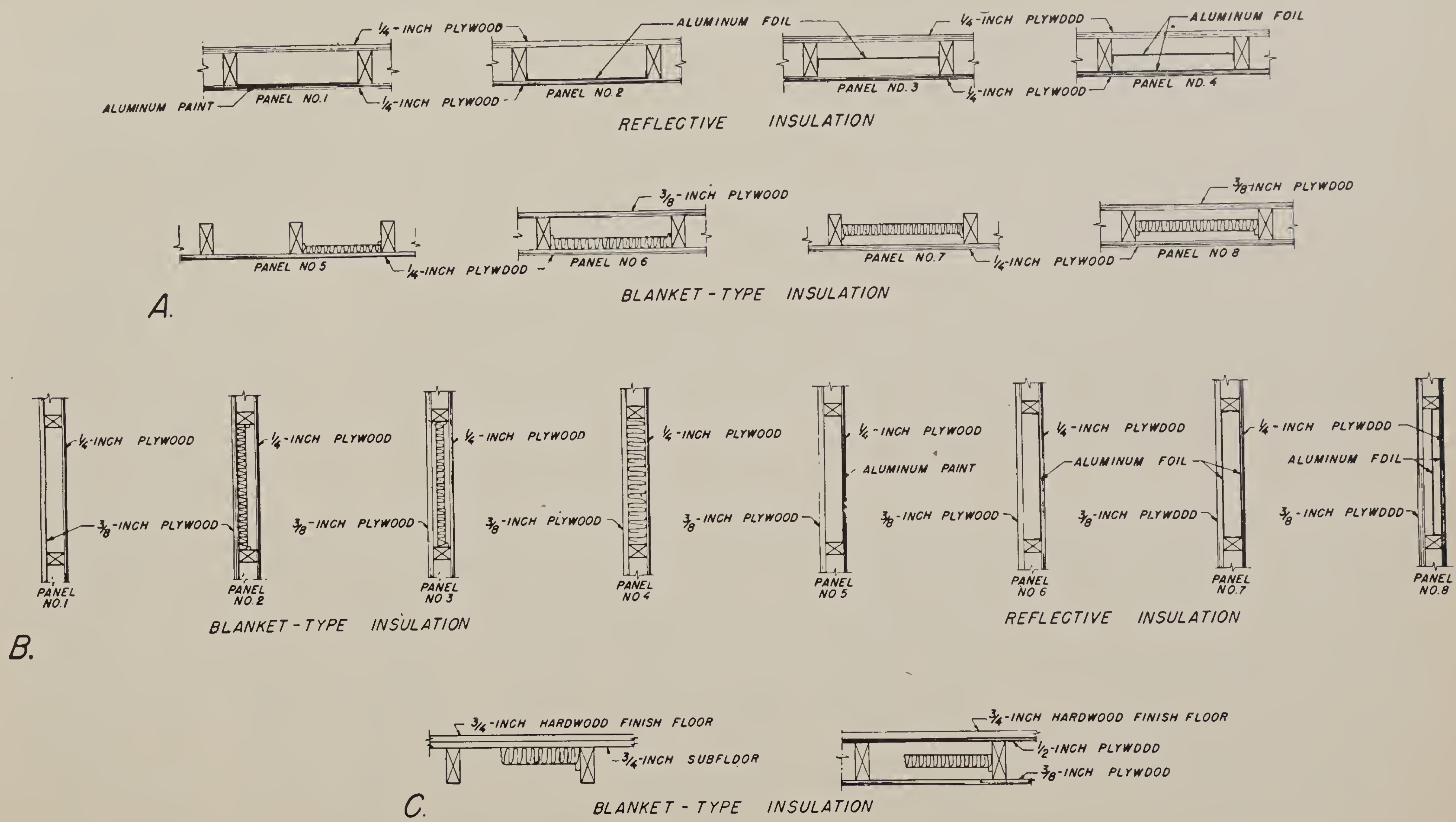

FIGURE 8-2.—Various test constructions typical of prefabricated ceiling, wall, and floor panels with different types and amounts of insulation to compare their relative insulating effectiveness (tables 8–1, 8–2, and 8–3 give U values for each construction shown). *A*, eight types of ceiling panel construction; panels Nos. 1 through 4 have reflective insulation, panels Nos. 5 through 8 blanket-type insulation. *B*, eight types of wall panel construction; panels Nos. 2 through 4 have blanket-type insulation, panels Nos. 5 through 8 reflective insulation. *C*, two types of floor construction with blanket-type insulation.

figure 8–2, *A*, are based on the assumption of a ventilated but unheated attic above. Even with ventilation, the roof reduces the heat loss, and for purposes of calculation it was assumed that the temperature in the attic was 20 percent of the difference between the indoor and outdoor temperature added to the outdoor temperature. The space below the floor usually receives more protection than the attic, and it was assumed that the temperature of the space below the floor was 40 percent of the difference between indoor and outdoor temperature added to the outdoor temperature in calculating the values given in table 8–3 for the two floor constructions shown in figure 8–2, *C*.

The heat loss through framing members of several thicknesses is shown in table 8–2 for wall panel No. 1 (*8–3*). If the surface temperature is substantially lower than the temperature of the space between framing members, dirt patterns (sec. 14.14) will outline the framing in the course of time. If elimination of dirt patterns were the only objective, an amount of insulation sufficient to supply a U value for the open space equal to that of the framing members should be used. Table 8–2 gives values for an uninsulated wall and for the same wall (panel No. 2) with various thicknesses of insulation not completely filling the wall. It is assumed that the air space shown is at least three-fourths inch. Panel No. 3 of figure 8–2, *B*, illustrates a wall with the insulation located midway between framing members, and the data for this wall construction given in table 8–2 are based on an air space of three-fourths inch.

Panel No. 4 (fig. 8–2 *B*) illustrates a panel in which the space is completely filled with insulation. Panels Nos. 5, 6, 7, and 8 (fig. 8–2, *B*) illustrate walls with reflective insulation. In panel No. 5, the inner surface of the plywood is painted with aluminum paint, panel No. 6

TABLE 8–1.—*Coefficients of heat transmission, heat loss, and interior temperatures calculated for ceiling panels with various types of insulation on the basis of design temperatures for various zones in the United States. Ceiling panels Nos. 1 through 4 have reflective insulation, panels Nos. 5 through 8 blanket-type insulation*

Panel construction [1]	Coefficient of heat transmission U	Comparative heat loss [2]	Interior surface temperature							
			Zone [3] A	Zone [3] B	Zone [3] C	Zone [3] D	Zone [3] E	Zone [3] F	Zone [3] G	Zone [3] H
		Percent	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
3⅝-inch joist	0.191		66.9	66.1	65.3	64.5	63.8	63.0	62.2	61.4
5⅝-inch joist	.138		67.7	67.2	66.6	66.1	65.5	64.9	64.4	63.8
Panel No. 1 (aluminum paint 1 side)	.376	85.5	63.9	62.3	60.8	59.3	57.7	56.2	54.7	53.1
Panel No. 2 (single-face aluminum foil 1 side)	.330	75.1	64.6	63.3	61.9	60.6	59.2	57.9	56.5	55.2
Panel No. 3 (double-face aluminum foil centered)	.206	46.8	66.6	65.8	65.0	64.1	63.3	62.4	61.6	60.8
Panel No. 4 (double-face aluminum foil centered plus single-face foil on warm side)	.204	46.4	66.7	65.8	65.0	64.2	63.3	62.5	61.7	60.8
Panel No. 5:										
No insulation	.787	100	57.2	53.9	50.7	47.5	44.3	41.1	37.9	34.7
½-inch insulation	.320	40.7	64.8	63.5	62.2	60.9	59.6	58.2	56.9	55.6
1-inch insulation	.201	25.5	66.7	65.9	65.1	64.3	63.4	62.6	61.8	61.0
2-inch insulation	.115	14.6	68.1	67.7	67.2	66.7	66.2	65.8	65.3	64.8
3-inch insulation	.081	10.3	68.7	68.3	68.0	67.7	67.4	67.0	66.7	66.4
3⅝-inch insulation	.068	8.6	68.9	68.6	68.3	68.1	67.8	67.5	67.2	66.9
Panel No. 6:										
No insulation	.416	100	63.2	61.5	59.8	58.1	56.4	54.7	53.0	51.3
½-inch insulation	.235	56.5	66.2	65.2	64.2	63.3	62.3	61.4	60.4	59.4
1-inch insulation	.164	39.5	67.3	66.7	66.0	65.3	64.6	64.0	63.3	62.6
2-inch insulation	.102	24.5	68.3	67.9	67.5	67.1	66.7	66.3	65.8	65.4
3-inch insulation	.074	17.8	68.8	68.5	68.2	67.9	67.6	67.3	67.0	66.7
3⅝-inch insulation	.063	15.1	69.0	68.7	68.5	68.2	67.9	67.7	67.4	67.2
Panel No. 7:										
½-inch insulation	.258	32.7	65.8	64.7	63.7	62.6	61.6	60.5	59.5	58.4
1-inch insulation	.174	22.1	67.2	66.4	65.7	65.0	64.3	63.6	62.9	62.2
2-inch insulation	.106	13.5	68.3	67.8	67.4	67.0	66.5	66.1	65.7	65.2
3-inch insulation	.076	9.7	68.8	68.4	68.1	67.8	67.5	67.2	66.9	66.6
Panel No. 8:										
½-inch insulation	.200	48.0	66.7	65.9	65.1	64.3	63.5	62.7	61.8	61.0
1-inch insulation	.146	35.0	67.6	67.0	66.4	65.8	65.2	64.6	64.0	63.4
2-inch insulation	.095	22.8	68.4	68.1	67.7	67.3	66.9	66.5	66.1	65.7
3-inch insulation	.070	16.8	68.9	68.6	68.3	68.0	67.7	67.4	67.1	66.9

[1] For detailed construction of panels see figure 8–2.
[2] Percent of heat loss compared to uninsulated panel.
[3] See figure 8–1.

Table 8–2.—*Coefficients of heat transmission, heat loss, and interior temperatures calculated for wall panels with various types of insulation on the basis of design temperatures for various zones in the United States. Interior surface temperatures given for panel No. 1 are for different thicknesses of framing members. Wall panels Nos. 2 through 4 have blanket-type insulation, panels Nos. 5 through 8 reflective insulation*

Panel construction [1]	Coefficient of heat transmission U	Comparative heat loss [2]	Interior surface temperature							
			Zone [3] A	Zone [3] B	Zone [3] C	Zone [3] D	Zone [3] E	Zone [3] F	Zone [3] G	Zone [3] H
		Percent	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Panel No. 1:										
1½-inch framing member	0.345	----------	61.6	59.5	57.5	55.4	53.3	51.2	49.1	47.0
2-inch framing member	.294	----------	62.9	61.1	59.3	57.5	55.7	54.0	52.2	50.4
2½-inch framing member	.256	----------	63.8	62.2	60.7	59.1	57.6	56.0	54.5	52.9
3-inch framing member	.227	----------	64.5	63.1	61.7	60.4	59.0	57.6	56.2	54.9
3⅝-inch framing member	.199	----------	65.2	64.0	62.8	61.6	60.4	59.1	57.9	56.7
Panel No. 2:										
No insulation	.433	100	59.5	56.9	54.3	51.6	49.0	46.4	43.8	41.1
½-inch insulation	.240	55	64.2	62.7	61.3	59.8	58.4	56.9	55.5	54.0
1-inch insulation	.166	38	66.0	65.0	64.0	63.0	62.0	60.9	59.9	58.9
2-inch insulation	.103	24	67.5	66.9	66.3	65.6	65.0	64.4	63.8	63.1
3-inch insulation	.075	17	68.2	67.7	67.3	66.8	66.4	65.9	65.5	65.0
Panel No. 3:										
½-inch insulation	.197	45	65.2	64.0	62.8	61.6	60.4	59.3	58.1	56.9
1-inch insulation	.145	33	66.5	65.6	64.7	63.8	63.0	62.1	61.2	60.3
2-inch insulation	.094	22	67.7	67.2	66.6	66.0	65.4	64.9	64.3	63.7
Panel No. 4:										
1½-inch insulation	.144	33	66.5	65.6	64.8	63.9	63.0	62.1	61.3	60.4
2-inch insulation	.114	26	67.2	66.5	65.9	65.2	64.5	63.8	63.1	62.4
2½-inch insulation	.094	22	67.7	67.2	66.6	66.0	65.4	64.9	64.3	63.7
3-inch insulation	.080	18	68.1	67.6	67.1	66.6	66.1	65.6	65.2	64.7
3⅝-inch insulation	.068	16	68.4	67.9	67.5	67.1	66.7	66.3	65.9	65.5
Panel No. 5 (aluminum paint 1 side)	.360	83	61.3	59.1	56.9	54.7	52.5	50.4	48.2	46.0
Panel No. 6 (single-face aluminum foil 1 side)	.298	69	62.8	61.0	59.2	57.4	55.6	53.7	51.9	50.1
Panel No. 7 (single-face aluminum foil 2 sides)	.291	67	62.9	61.2	59.4	57.7	55.9	54.1	52.4	50.6
Panel No. 8 (double-face aluminum foil centered plus single-face foil on warm side)	.171	40	65.9	64.8	63.8	62.7	61.7	60.7	59.6	58.6

[1] For detailed construction of panels see figure 8–2.
[2] Percent of heat loss compared to uninsulated panel.
[3] See figure 8–1.

Table 8–3.—*Coefficients of heat transmission, heat loss, and interior temperatures calculated for floor panels with blanket-type insulation on the basis of design temperatures for various zones in the United States*

Panel construction [1]	Coefficient of heat transmission U	Comparative heat loss [2]	Interior surface temperature							
			Zone [3] A	Zone [3] B	Zone [3] C	Zone [3] D	Zone [3] E	Zone [3] F	Zone [3] G	Zone [3] H
		Percent	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*	° *F.*
Panel No. 1:										
No insulation	0.328	100	63.4	61.8	60.2	58.5	56.9	55.2	53.6	52.0
½-inch insulation	.204	62.2	65.9	64.9	63.9	62.9	61.8	60.8	59.8	58.8
1-inch insulation	.148	45.2	67.0	66.3	65.6	64.8	64.1	63.3	62.6	61.9
2-inch insulation	.095	29.0	68.1	67.6	67.1	66.7	66.2	65.7	65.2	64.8
3-inch insulation	.071	21.6	68.6	68.2	67.9	67.5	67.2	66.8	66.4	66.1
Panel No. 2:										
No insulation	.239	100	65.2	64.0	62.8	61.6	60.4	59.2	58.0	56.8
½-inch insulation	.140	58.6	67.2	66.5	65.8	65.1	64.4	63.7	63.0	62.3
1-inch insulation	.111	46.4	67.8	67.2	66.7	66.1	65.6	65.0	64.4	63.9
2-inch insulation	.079	33.0	68.4	68.0	67.6	67.2	66.8	66.4	66.0	65.7
3-inch insulation	.061	25.5	68.8	68.5	68.2	67.9	67.6	67.3	67.0	66.6

[1] For detailed construction of panels see figure 8–2.
[2] Percent of heat loss compared to uninsulated panel.
[3] See figure 8–1.

has reflective insulation with one surface exposed, panel No. 7 reflective insulation with two surfaces exposed and opposed to one another, and double-faced reflective insulation is centered in panel No. 8 together with an additional foil within the inner panel cover, one face of which is exposed. Those panels having surface temperatures of 64° F. or higher would be in the acceptable comfort range. It becomes evident that, if the coefficient of transmission

of the framing members is balanced with that of the space between members, an interior surface temperature will result that is below the desired comfort range.

Fuel economy alone justifies the use of an amount of insulation sufficient to attain adequate comfort temperatures, particularly in zones, D, E, F, G, and H.

A prefabricator producing houses for a limited area can determine the amount of insulation that would be adequate for comfort and fuel economy in that area. For example, assuming a surface temperature of walls not more than 6° F. different from a room atmospheric temperature of 70° F., the maximum coefficient of transmission for zone A would be about 0.248; that for zone B about 0.200; that for zone C about 0.164; that for zone D about 0.143; that for zone E about 0.125; that for zone F about 0.111; that for zone G about 0.098; and that for zone H about 0.084.

Protection against summer heat is no doubt far more important in zones A, B, and C than is protection against cold winter weather. As the insulation serves to protect against heat transfer during both summer and winter, however, the maximum coefficients of transmission given for zone C (tables 8–1 and 8–2) could well be applied in both zone A and zone B to attain reasonable protection from summer heat. The types of insulation which give better resistance to downward heat flow should be given consideration where such need is paramount.

Where a prefabricator finds it necessary to standardize a design for use in any zone, the coefficient of transmission should preferably be equal to that recommended for zone F, or a –20° F. design temperature.

8.112. Types of Insulation.—The general types of insulation used in prefabricated houses are blanket, batt, rigid, fill, and reflective (*8–2*). Flexible insulation is manufactured in the form of blankets with one or both surfaces covered with paper. Some of the covering materials are coated with asphalt, to which the insulation adheres and which is intended to serve as a vapor barrier (sec. 8.2). The blanket type is generally tacked between framing members during the assembly of the panel. Flexible insulation is also obtainable without the paper covering, in which case it is usually called batt insulation. Blanket insulation is commonly supplied in thicknesses of ½, 1, 2, and 3 inches, batt insulation in thicknesses of 2 inches and 3⅝ inches. The materials used may be mineral wool, which is a fibrous material made from slag, rock, or glass sand; or processed vegetable fibers, such as wood, cotton, and seaweed (sec. 3.420).

Fill-type insulation is a loose product usually supplied in bags and may be poured or packed by hand into the spaces to be insulated. It is made from about the same materials as flexible insulation.

Insulating boards (sec. 3.420) are available in thicknesses of one-half or three-fourths inch or in multiples of these thicknesses obtained by joining boards together. Because of their higher density, the board materials are somewhat less efficient as insulation per unit of thickness than are the flexible or fill-type materials.

Reflective insulation is a term applied to materials that have a surface that reflects heat. All surfaces have this property to some degree, but certain materials have it to a high degree. Among these are aluminum, coated steel, and certain other bright-surfaced materials (*8–6*). Aluminum paint has considerable reflective value, though much less than aluminum foil (*8–11*). To be effective, the bright surface must be exposed to an air space, preferably three-fourths inch or more. The metal foil makes an excellent vapor barrier and is sometimes used as the covering sheet for flexible or blanket insulation. If so installed that the foil surface faces an air space, it adds to the total insulation of the part involved.

8.12. Thermal Properties of Materials.—The Forest Products Laboratory has made careful determinations of the thermal conductivity of wood at various moisture content values (*8–5*). These tests furnished sufficient data on the relationship between conductivity, specific gravity, and moisture content to make it possible to compute the approximate thermal conductivity for any wood for which the specific gravity is known and for which the moisture content can be determined or assumed. The values given in most tables of conductivity values are for some stated moisture content.

Heat conductivity, represented by the symbol K, is defined as the amount of heat in British thermal units that will pass in 1 hour through 1 square foot of the material 1 inch thick per

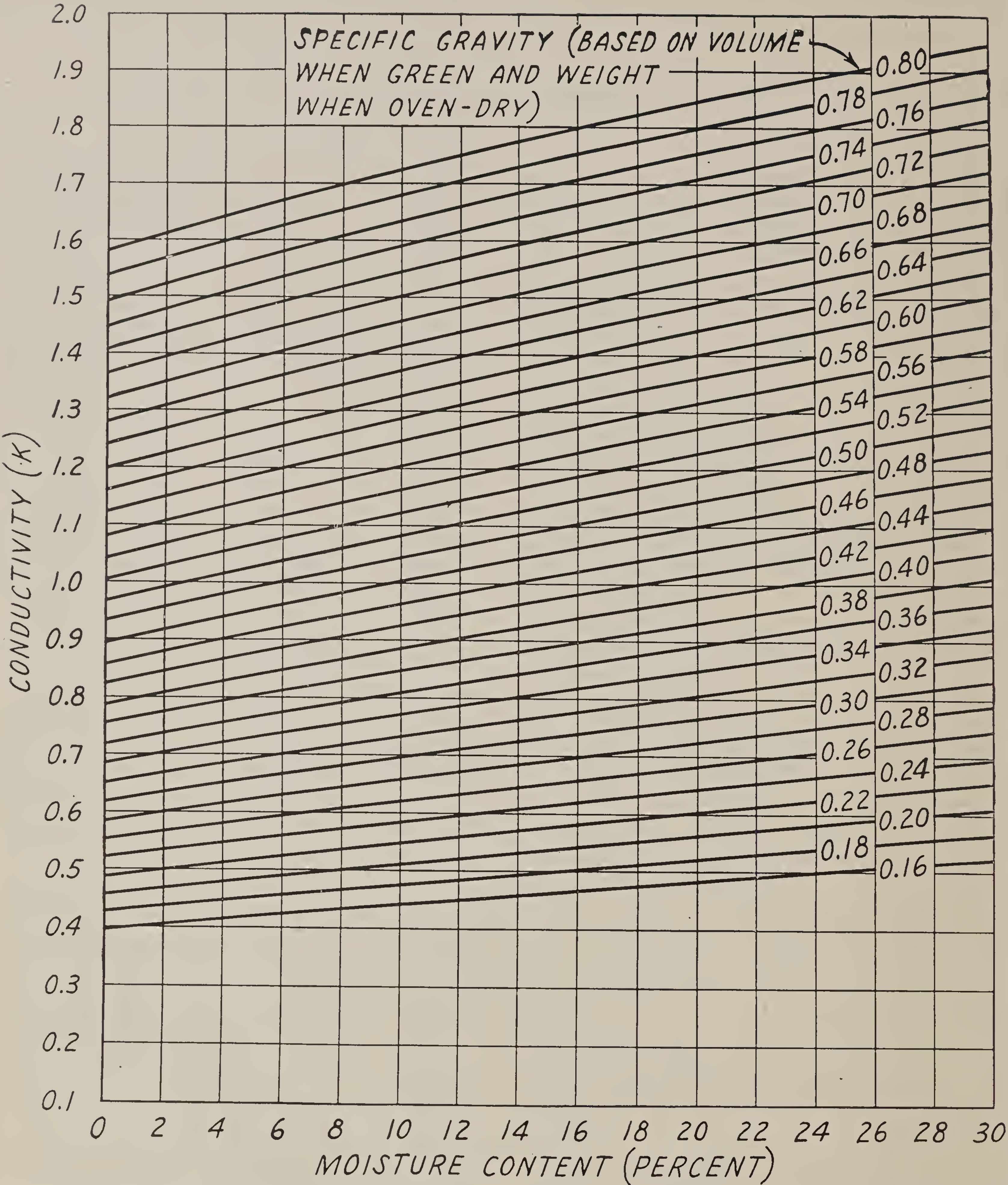

FIGURE 8–3.—Chart for determining heat conductivity of wood of a known specific gravity and moisture content. Read upward along moisture content line to intersection with proper specific gravity line, then read conductivity value on left-hand scale opposite intersection point.

1° F. temperature difference between the faces of the material.

The thermal conductivity of a given wood at a known or assumed moisture content can be determined from figure 8–3. Since published average specific gravities are commonly based on volume when green, these specific gravities were used in the preparation of figure 8–3.

To use this chart: Obtain the average specific gravity for the wood under consideration from table 3–1. On the chart, follow a vertical line corresponding to the known or assumed moisture content of the wood upward until it intersects the sloping line corresponding to the specific gravity of the wood. The reading on the vertical scale at the left of this intersection point is the desired thermal conductivity, *K*, for the wood at the assumed moisture content.

The specific gravity data of table 3–1 are average values for the species listed and there are, of course, appreciable variations in specific gravity between boards or shipments of the same species.

The conductivity value for plywood is essentially the same as that for solid wood of the same thickness.

8.120. Method of Computing Thermal Conductivities.—Testing of all combinations of building materials to determine their thermal properties is impracticable. Thermal efficiency can, however, be calculated when the materials or air spaces used have known values for conductivity or conductance. The over-all, or U, value obtained (sec. 8.111) includes the surface conductances on both sides of the material or combination of materials and air spaces for which it is calculated.

The method used in computing the U value is as follows: Add the resistance of each material, exposed surface, and air space in the given section, using values given in table 8–4. The sum of these resistances divided into 1 (the reciprocal of the sum) gives the coefficient of transmission (U). Where reflective insulation is used, the value in table 8–4 includes the air space.

TABLE 8–4.—*Values recommended for computing over-all coefficients of thermal transmission. Values are expressed in British thermal units per hour per square foot per 1° F. temperature difference on opposite sides of the material. Unless otherwise noted, are per inch of thickness* [1].

Material	Description	Conductivity or conductance	Resistivity or resistance
Air spaces			
Bounded by ordinary materials	¾ inch or more in width		
	Vertical	1.10	[2] .91
	Horizontal, heat flow up	1.31	[2] .76
	Horizontal, heat flow down	.945	1.06
Faced one side with aluminum paint	¾ inch or more in width		
	Vertical	.725	[2] 1.38
	Horizontal, heat flow up	.88	[2] 1.14
	Horizontal, heat flow down	.435	[2] 2.30
Faced one side with aluminum foil	¾ inch or more in width		
	Vertical	.51	[2] 1.96
	Horizontal, heat flow up	.66	[2] 1.51
	Horizontal, heat flow down	.20	[2] 4.95
Faced both sides with aluminum foil	¾ inch or more in width		
	Vertical	.49	[2] 2.04
	Horizontal, heat flow up	.64	[2] 1.56
	Horizontal, heat flow down	.18	[2] 5.50
Space divided by double reflective aluminum foil	1½ inches or more in width		
	Vertical	.23	[2] 4.38
	Horizontal, heat flow up	.30	[2] 3.32
	Horizontal, heat flow down	.09	[2] 11.14
Space divided by double reflective aluminum foil plus single reflective foil on warm side	1½ inches or more in width		
	Vertical	.22	[2] 4.46
	Horizontal, heat flow up	.295	[2] 3.38
Exterior finishes (frame walls)			
Brick veneer	4 inches thick (nominal)	2.27	[2] .44
Stucco	1 inch thick	12.50	.08
Wood shingles		1.28	[2] .78
Southern yellow pine lap siding		1.28	[2] .78
Insulating materials			
Aluminum foil	(See Air Spaces)		
Batts and blankets	Made from mineral or vegetable fiber or animal hair enclosed or open	.27	3.70
Cork board	No added binder	.30	3.33

TABLE 8-4.—*Values recommended for computing over-all coefficients of thermal transmission. Values are expressed in British thermal units per hour per square foot per 1° F. temperature difference on opposite sides of the material. Unless otherwise noted, the values are per inch of thickness*[1].—Continued.

Material	Description	Conductivity or conductance	Resistivity or resistance
Insulating board	Vegetable fiber	.33	3.03
Mineral wool	Fibers made from rock slag or glass	.27	3.70
Vermiculite	Expanded	.48	2.08
Sawdust and shavings		.41	2.44
Interior finishes			
Composition wallboard	3/16 to 3/8 inch thick	0.50	2.00
Gypsum plaster		3.30	.30
Gypsum board, ⅜ inch	Plain or decorated	3.70	[2] .27
Gypsum lath and plaster	Plaster, assumed ½ inch	2.40	[2] .42
Insulating board (½ inch)	Plain or decorated	.66	[2] 1.52
Insulating board lath (½ inch) and plaster	Plaster, assumed ½ inch	.60	[2] 1.67
Insulating board lath (1 inch) and plaster	Plaster, assumed ½ inch	.31	[2] 3.18
Metal lath and plaster	Plaster, assumed ¾ inch	4.40	[2] .23
Plywood	(See values for Wood)		
Wood lath and plaster		2.50	[2] .40
Masonry materials			
Brick	Common, assumed 4 inches thick	1.25	[2] .80
Brick	Face, assumed 4 inches thick	2.27	[2] .44
Cement mortar		12.00	.08
4-inch clay tile. Hollow		1.00	[2] 1.00
6-inch clay tile. Hollow		.64	[2] 1.57
8-inch clay tile. Hollow		.60	[2] 1.67
10-inch clay tile. Hollow		.58	[2] 1.72
12-inch clay tile. Hollow		.40	[2] 2.50
Concrete	Light-weight aggregate [3]	2.50	.40
Concrete	Cinder aggregate	4.09	.22
Concrete	Sand and gravel aggregate	12.00	.08
8-inch concrete blocks	Hollow, light-weight aggregate [3]	.50	[2] 2.00
12-inch concrete blocks	do	.47	[2] 2.13
4-inch concrete blocks	Hollow, cinder aggregate	1.00	[2] 1.00
8-inch concrete blocks	do	.60	[2] 1.66
12-inch concrete blocks	do	.53	[2] 1.88
8-inch concrete blocks	Hollow, sand and gravel aggregate	1.00	[2] 1.00
12-inch concrete blocks	do	.80	[2] 1.25
3-inch gypsum tile	Hollow	.61	[2] 1.64
4-inch gypsum tile	do	.46	[2] 2.18
Tile and terrazzo	For flooring	12.00	.08
Stone		12.00	.08
Roofing materials			
Asbestos shingles		6.00	[2] .17
Asphalt shingles		6.50	[2] .15
Built-up roofing	Assumed thickness ⅜ inch	3.53	[2] .28
Heavy roll roofing		6.50	[2] .15
Slate	Assumed thickness ½ inch	20.00	[2] .05
Wood shingles		1.28	[2] .78
Sheathing			
Gypsum, ½ inch		2.82	[2] .35
Insulating board (25/32 inch)		.42	[2] 2.37
Wood (25/32 inch)		1.02	[2] .98
Wood (25/32 inch) plus building paper		.86	[2] 1.16
Surfaces			
Inside surfaces	Ordinary materials, still air		
	Vertical	1.65	[2] .61
	Horizontal, heat flow up	1.96	[2] .51
	Horizontal, heat flow down	1.20	[2] .83
Outside surfaces	Ordinary materials, 15 mph wind	6.00	[2] .17
	Reflective materials, 15 mph wind	5.25	[2] .19
Surface in ventilated attic	Ordinary material, heat flow up	1.95	[2] .51
	Reflective material, heat flow up	1.16	[2] .86
Surface in ventilated crawl space	Ordinary material, heat flow down	1.21	[2] .83
	Reflective material, heat flow down	.44	[2] 2.27
Frame walls			
Wood sheathing (25/32 inch), building paper, and bevel siding		.50	[2] 2.00

[1] Table based on data from 1945 American Society of Heating and Ventilating Engineers Guide, with additions.
[2] Values for thickness stated, not per inch.
[3] Expanded slag, burned clay, or pumice.

Example: The over-all U value of wall panel No. 2 of figure 8–2, *B*, with ½-inch insulation is calculated as follows:

Exterior surface resistance (15 mph wind movement)	0.17
Exterior plywood ⅜-inch Douglas-fir (moisture content assumed at 11 percent	.37
½-inch blanket insulation (one-half the value for 1-inch blanket)	1.85
Air space (¾ inch wide or more)	.91
Interior plywood (¼-inch Douglas-fir)	.25
Inside surface resistance	.61
Over-all resistance	4.16

The over-all coefficient of thermal transmission, then, is:

$$U = \frac{1}{4.16} = 0.24$$

Inside Surface Temperature.—The inside surface temperature may be computed by the following formulas:

For horizontal heat flow (through walls):

$$T_s = t_i - \frac{U}{1.65}(t_i - t_o) \qquad (1)$$

For vertical heat flow upward (through ceilings in winter):

$$T_s = t_i - \frac{U}{1.96}(t_i - t_o) \qquad (2)$$

For vertical heat flow downward (through ceilings in summer or through floors in winter):

$$T_s = t_i - \frac{U}{1.2}(t_i - t_o) \qquad (3)$$

Where t_i is the temperature of the inside air, generally assumed at 70° F., t_o is the temperature of the outside air, and $(t_i—t_o)$ is the difference between the temperature of the inside and outside air. The values 1.65, 1.96, and 1.2 are the surface conductances for walls, ceilings, and floors respectively.

Temperatures for other surfaces in a composite structural unit can be computed by adding the conductance values between the inside air and the desired surface and substituting this value for the surface conductances used in the above formulas.

8.13. Storm Doors and Storm Sash.—The heat loss through doors and windows is generally much greater per square foot of surface than that through walls, ceilings, or floors. The coefficients of transmission generally used for doors are given in table 8–5.

TABLE 8–5.—*Coefficients of thermal transmission through doors of different thicknesses with and without wood storm doors*

Actual thickness	Without storm door	With storm door
Inches	*U*	*U*
1 1/16	0.59	0.38
1⅜	.51	.35
1¾	.46	.32

The coefficients of thermal transmission for windows are:

Type of window	
Single	1.13
Double (storm sash)	.45
Double glazing (2 thicknesses of glass on one sash)	.65

Doors and windows represent about 20 percent of the surface of exterior walls. The loss of heat through glass and door surfaces, however, represents a much higher percentage of the total for the house unless these surfaces are protected with storm doors, storm sash, or double glazing. The cold glass surface can also be the cause of considerable discomfort due to radiation from the body to the glass. Condensation collecting on the windows not only obscures the outlook but also wets the sash and window stool and stains the walls.

Storm doors and double-glazed windows reduce the heat losses through these surfaces by approximately one-half. The inside surface temperatures of openings so protected are much higher, eliminating the condensation and adding materially to comfort. Cold-weather protection offered by storm doors and storm sash should be included in all houses in zones D, E, F, G, and H.

8.2. CONDENSATION WITHIN WALLS AND ROOFS.

8.20. General.—The formation of sweat or frost on the inner face of windows not protected by storm sash is a familiar example of how water vapor present in the air of a room condenses in cold weather. When outside temperatures are low, water vapor under certain conditions will pass through inner wall or ceiling surfaces and condense within the wall or roof space on some colder surface. Moisture that collects within walls during cold weather is a common cause of exterior paint failure (ch. 7) and may cause decay in framing members and exterior wall covering. Moisture collecting in attics and under flat roofs drips back

and stains the ceiling below and may foster decay in the roof members. Millions of dollars are spent every year in painting, redecoration, maintenance, and repairs because of disfigurement and damage caused by condensation in cold weather (*8–8*), (*8–10*).

8.21. Vapor Sources.—There is no mystery regarding the source of moisture. Water vapor is added to the atmosphere within a house from many sources, such as cooking, dishwashing, laundry work, bathing, respiration, and evaporation from flowers and plants. Moisture is liberated by unvented gas heaters and gas stoves. Often the humidity is raised in homes during cold weather by the evaporation of water from a furnace or radiator pan. Some houses are equipped with winter air-conditioning devices that automatically maintain the relative humidity at some selected condition that is presumed to be beneficial to health and comfort.

Older homes are so constructed that generaly there is considerable air infiltration and outleakage of vapor, and as a result the relative humidity inside the house is consistently low during cold weather. It is common practice today to build more air-tight houses than were commonly built 15 or more years ago, the reduction in air infiltration being obtained partly by use of weatherstrips and storm sash and partly by means of the construction methods and materials used.

Tight construction and a minimum of air infiltration are characteristic of prefabricated houses. The smaller volume of many modern houses, both prefabricated and conventional, is a contributing factor. There is less opportunity for vapor liberated within the house to escape. The relative humidity in such houses is higher than that in older houses that are less resistant to air infiltration.

Even though tight construction, weatherstripping, insulation, and other factors increase the hazards of condensation, such measures are desirable. Proper construction can minimize the condensation problem.

There is a characteristic relationship in all houses between indoor relative humidity and outdoor temperature. The humidity is generally high indoors when outdoor temperatures are high, and decreases as outdoor temperatures decrease. The order of this relationship is shown in figure 8–4 for old houses, for an average house, and for a modern, tightly constructed house. The curve for tight houses represents the conditions that may be expected in most prefabricated houses. In houses where winter air conditioning involves automatic control of relative humidity, hygrostats are used to maintain some established minimum humidity. An example illustrating automatically controlled indoor relative humidity is also shown in figure 8–4 with the indoor humidity set at 40 percent.

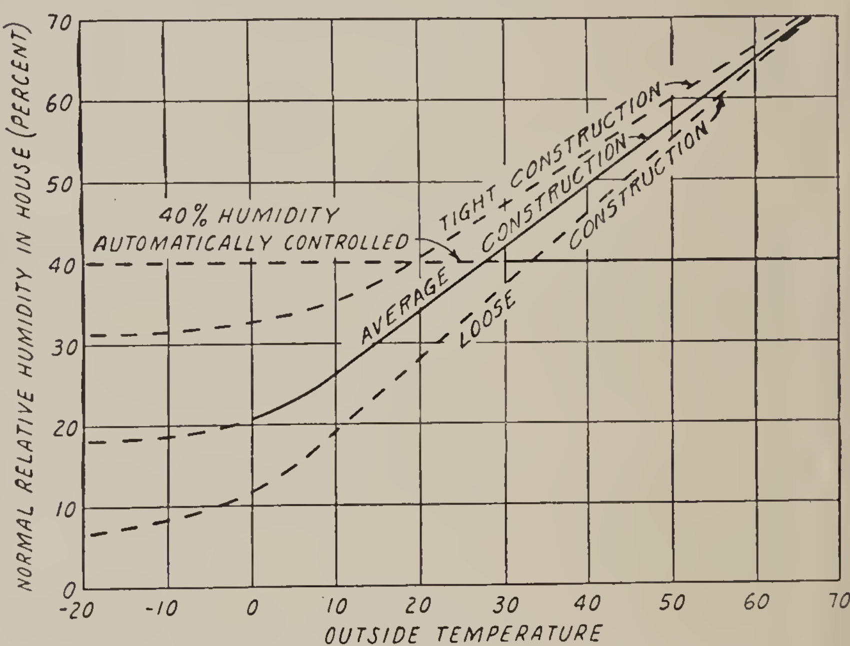

FIGURE 8–4.—Relation of normal relative humidity within a house to outdoor temperature, for three types of house construction.

These temperature-humidity relationships are by no means uniform. For various reasons they vary widely even among houses of similar construction. In building projects where a large number of houses of more or less identical construction are involved, some may show no evidence of condensation, others may show it only after unusually cold winters, and still others may show evidence several times each winter or after every period of cold weather. These differences in otherwise comparable houses are due not to a variation in construction but to variations in the customs or habits of the occupants. Some householders prefer to heat their houses to higher temperatures than do others—an important contributing factor, particularly where temperatures higher than 75° F. are maintained. In homes with babies, the extra laundry work, cooking, and dishwashing contribute moisture.

8.22. Effect of Insulation on Condensation.—Insulation does not "draw water," but it can con-

tribute to the accumulation of condensation. Because insulation reduces heat losses, the temperature of those parts of a wall on the cold side of the insulation will be lower than if no insulation were used. This means it is more likely that material on the cold side will be below the dewpoint temperature of the room and hence there is likely to be more condensation on this material than when no insulation is used. Since insulation is important as a means of conserving heat or fuel and creating comfortable living conditions, its use should not be condemned because of its influence on condensation.

Condensation is by no means limited to side walls. It may also occur in attic spaces or on the under side of flat roofs. The condensation collects as frost or ice on the under side of the roof boards, on projecting shingle nails, and sometimes between the roof sheathing and roof covering. On bright, sunshiny days, even at low temperatures, the frost melts and water drops from the roof to the ceiling below, where it causes water stains and other damage. Mold, blue stain, and often decay develop in the roof members, and repeated wetting may cause serious damage to the ceiling material.

8.220. Use of Louvers.—Condensation in attics has been so common that it is almost standard practice for builders to install louvered openings in the gabled ends of houses in order to provide ventilation through attic spaces (fig. 8–5). When these openings function properly, there is generally little evidence of condensation. Some, however, are too small (fig. 8–6), some do not face prevailing winds, and for numerous other reasons many fail to function as intended.

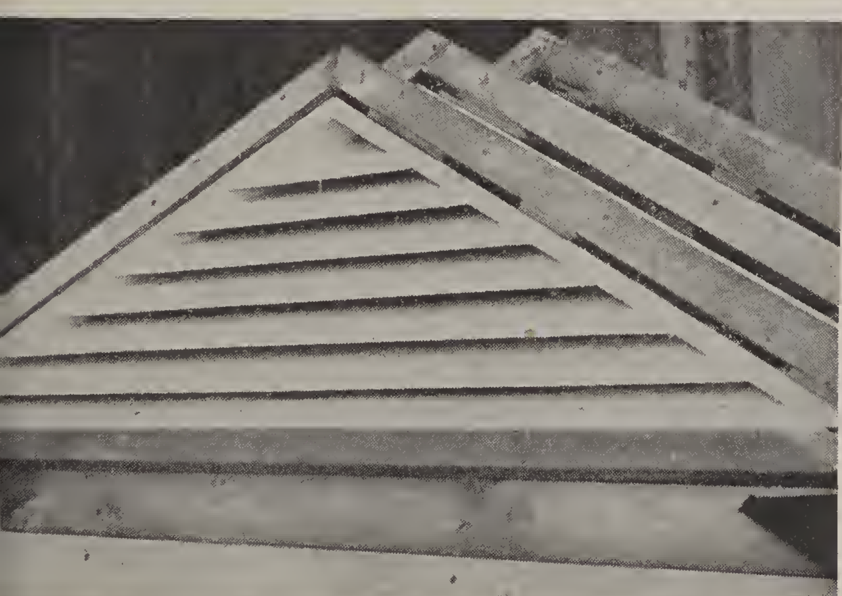

FIGURE 8–5.—Triangular louvered openings in the peak of a gable. Openings in this location are more efficient than those located lower down in the gable.

FIGURE 8–6.—Decorative type of louvered opening. Often the area available for air movement through side wall louvers is restricted because of the shape.

Louvered openings cannot be installed in all types of roofs, particularly hip roofs and some types of flat roofs. As usually constructed, such roofs have no provision for ventilation. Figure 8–7 shows how one builder has provided roof panel ventilation by using partial headers in his roof panels. Even where provision for ventilation is provided by the builder, it often happens that the householder will close the open-

FIGURE 8–7.—Method of ventilating long flat roof panels. Headers are installed so as to permit an opening about 1 inch deep across width of panel at either end, so that air can circulate above insulation.

ings to conserve heat or for some other reason, and the intended protection is lost. Purchasers should be cautioned by the builder against such practices.

8.221. Condensation on Fastenings.—Insofar as possible, joints and fastenings should be made so that any metal used is covered with a maximum of material having good thermal properties; otherwise, condensation may collect on the interior surface over such fastenings. In thin walls, condensation may collect on the heads of nails used to attach plywood or other inner wall covering material to the framing members, causing disfiguring rust stains. Such spots may appear even when the nails are set and puttied.

8.23. Vapor Barriers. — The Forest Products Laboratory has been receiving reports of condensation in houses from various parts of the United States for many years. In normal or mild winters, most of these reports come from areas north of a line roughly projected east and west from the Ohio River. After a severe winter, such as occurs every 4 or 5 years, reports are more numerous and include many from areas farther south. On the basis of these reports, it has been established that condensation problems may be expected in those parts of the country where the average January temperature, according to the U. S. Weather Bureau records, is 35° F. or lower.

Prefabricated houses erected north of the 35° F. January isotherm (fig. 8–8) should be provided with some positive form of protection against normal winter condensation. Houses erected in areas south of this line where condensation problems have been experienced should also be protected. This can be best accomplished by installing vapor barriers on the warm side of the construction. These barriers stop or greatly retard the transmission of water vapor into the wall, attic, or roof. If the barrier is so located that the temperature on its warm side is above the dewpoint temperature of the room, there will be no condensation on the barrier.

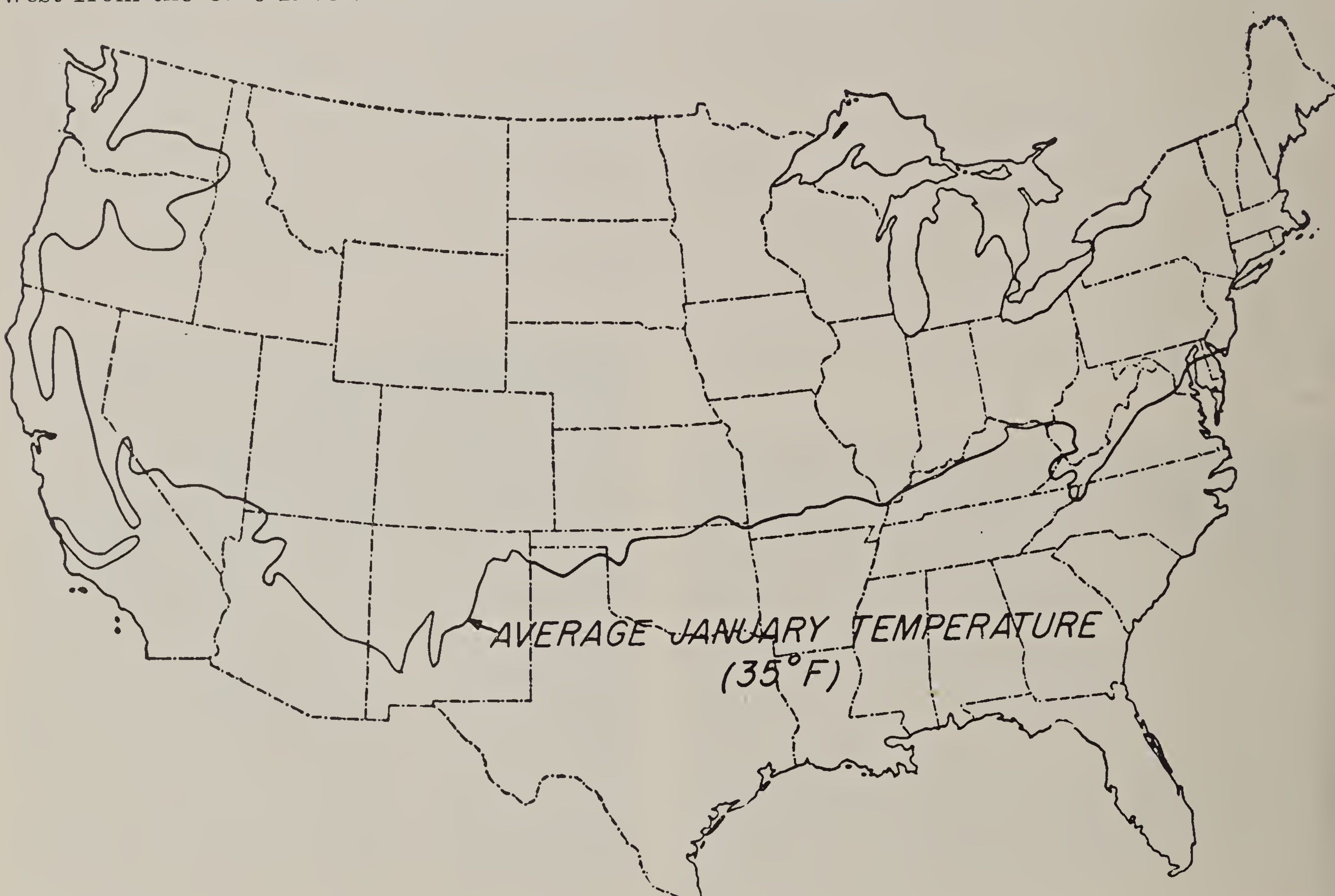

FIGURE 8–8.—Winter condensation problems occur in unprotected houses in those parts of the country where the average temperature for January is 35° F. or less. Vapor barriers should be used in all new homes built in those areas.

FIGURE 8–9.—Foil is an excellent vapor barrier. It should, however, be near the inner wall. As shown, it is against the outer wall, where the temperature may be below the dewpoint, in which case it serves as a condensing surface.

Barriers may be of two classes: (1) Sheet materials generally located back of the inner wall covering and attached to the framing members; and (2) suitable paints or coatings on the inner wall surface. The sheet materials include various types of comparatively inexpensive building papers: (1) Asphalt-coated kraft paper having a bright, shiny surface, sold in rolls of 500 square feet and weighing about 50 pounds per roll; (2) duplex sheets consisting of 2 sheets of plain kraft paper cemented together with asphalt; (3) double-faced aluminum foil mounted on a paper core (fig. 8–9); and (4) insulating materials mounted on a vapor-resistant paper. The laminated or duplex kraft papers are made in a variety of weights of paper and asphalt (*8–4*).

In duplex papers it is common practice to designate the product by the weight of paper and laminations per ream (480 square feet). For example a "30-50-60 paper" would be one containing, per ream, a 30-pound paper in one sheet, a 50-pound asphalt lamination, and a 60-pound paper in the other sheet. Some duplex papers contain strings, usually of hemp or jute, in the lamination to impart tear resistance. A "creped duplex" paper is one in which the sheets are creped before or after assembly.

The plain duplex is less expensive and generally more vapor-resistant than the reinforced or creped papers. The asphalt lamination should be 50 pounds or more and the surface papers 30 pounds or more. On this basis, a paper classified as a 30-50-30 grade would be satisfactory.

Not all of the backup papers used on insulation are equal to the resistance offered by the separate barriers. Where there is any question as to their resistance, it would be well to use the separate barriers between the insulation and inner covering of the wall or ceiling.

Paints that are effective barriers include (1) two coats of aluminum paint or (2) two coats of asphalt paint applied to the back of plywood used for inner wall or ceiling covering; and (3) one coat of aluminum paint covered with a coat of an oil paint of good quality for face finishing of inner wall or ceiling coverings. Some of the phenol resin-impregnated papers coming into use as facing over plywood are also effective as moisture barriers.

Vapor barrier material should be installed so that joints between sections or strips are adequately lapped and sealed to prevent filtration of moisture through the joints (sec. 14.43).

8.24. Requirements for Louvers, Ventilators.—Some vapor is transmitted through most barriers of good quality, but the amount is small enough so that it generally can escape outward through side walls without causing any problem. As roofing materials are generally made of a material that is in itself a good barrier, vapor entering roof spaces cannot escape readily unless the space is ventilated. Ventilation of attics and roof spaces is hence desirable.

Louvered openings in the gable ends of attics should have a minimum total free area not less than one-half square inch per square foot of area at the exterior plate line. This is an absolute minimum for the purpose of preventing condensation only. A triangular opening (fig. 8–5) in the peak of the gable is more efficient than an opening some distance below the peak (fig. 8–6). Roofs having more than two gables should have a louvered opening in each gable.

Hip roofs, where louvered openings cannot be used, can be vented by various means. Globe ventilators in the ridge, with inlet openings under the cornice around the perimeter of the house (fig. 8–10), are efficient. For each 15 to 18 square feet of ceiling area, 1 square inch of area in the ventilator should be allowed. An 8-inch ventilator is sufficient for a house having a ceiling area of 24 by 36 feet. For such a house, inlets should be provided under the eaves equal to two openings on each side of 6 inches by 8 inches. These openings may be covered with a metal grille.

Ventilation should be provided in flat roofs in accordance with the roof framing. Where one solid member is used for both ceiling and roof joist, there is no intercommunication between joist spaces, and openings should be provided for each space (fig. 8–7). Flat roofs that overhang the wall below can often be provided with openings under the overhang. A continuous opening three-fourths inch wide should be sufficient for a house of average size.

8.25. Venting Openings in Framework.—Some designers of prefabricated houses have attempted to eliminate the vapor barrier in side walls and have provided small holes in the framing members that are intended to provide ventilation for the removal of moisture. Side-wall ventilation, to be effective, requires that there be openings

FIGURE 8–10.—Ventilators located under overhanging roofs are particularly suited for use as air intakes in hip roofs. Exhaust ventilators should be located in the peak of the roof.

of ample size at the bottom and top of the wall, one to let air in, the other to let it escape. All such vents should open to the outside. Air movement will depend for the most part upon temperature differences in the height of the panel and to a minor degree upon exterior wind forces. The latter are unreliable. Nor will air move freely through small openings or where frictional resistance is high when the only force is that created by temperature differences. To be effective, the openings or spaces through framing members and those between insulation and exterior-wall covering materials should be at least three-fourths inch wide in the least dimension.

Since the framing around windows and doors cuts off the vertical circulation and temperature differences cannot be depended upon to create a horizontal circulation, the spaces above and below such openings cannot be adequately ventilated even though ventilating holes that lead into panels having no windows or doors are provided in the vertical framing members. Even where adequate openings for ventilation are provided, ventilation may be obstructed by hoar-frost and ice, which gather during very cold weather faster than they can be carried away. If ventilation sufficient to be effective is obtained, there will be some loss in insulating value of the exterior wall, which must be compensated for by increasing the amount of insulation used.

8.26. Door, Window Protection.—Condensation on windows and doors often causes water stains on decorations and sometimes gives rise to decay in sash and frames. The most practical method of protection against such condensation is the use of double windows, or storm sash and storm doors, during cold weather. For windows, glass lights can be obtained that are made of two pieces of glass separated about one-half inch and sealed on the edges. Though not equal to good storm sash in reducing heat loss, they are much superior to single lights. Being permanently in place, they are not a yearly maintenance problem. Sometimes windows are set in frames without movable sash, in which case

FIGURE 8–11.—Louvered ventilators installed under windows fixed in place.

it is common practice to install louvered ventilators below or above the windows (fig. 8–11).

8.27. Crawl Spaces.—Ventilation requirments for crawl spaces underneath basementless houses are discussed in sections 6.12 and 14.13.

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SEASONING AND STORAGE OF HOUSING MATERIALS

9.0. GENERAL.—Lumber, plywood, and most other wood-base materials used in prefabricated housing are subject to dimensional change with changes in their moisture content (sec. 3.6). For this reason, these materials should be dried to approximately the moisture content they will attain in use before they are fabricated into house parts. The process by which wood is dried to a desired moisture content is called seasoning.

Adequately seasoned lumber is even more important in the production of panels or sections for prefabricated houses than it is in conventional construction. Shrinking or swelling of framing members of such panel constructions exerts powerful stresses upon glue joints and may cause delamination. The effects of shrinkage and swelling, moreover, may change the dimensions and shape of panels, even between the time of manufacture and assembly, sufficiently to create serious difficulties when assembling panels at the building site. The effects of dimensional changes in panels after erection are manifested by open joints, warped or bulged floors, cracked plaster, torn wallpaper, checks in plywood, paint failure, and general weakening of the structure.

Second only to good seasoning is the importance of proper storage of dried lumber and manufactured house parts. Exposure of carefully dried and manufactured panels or other parts to excessive humidity, rain, snow, or similar hazards between the time of manufacture and construction of the house can seriously damage the parts by causing a regain of moisture that will cause swelling, dimensional changes, warping, and damage to finish.

The objective of all seasoning is to bring lumber from the green state to a moisture content that will be in equilibrium with the average conditions of temperature and relative humidity in which it will be used. For most parts of the United States, this equilibrium condition is affected by the seasons. Between winter and summer, therefore, wood in use will lose or gain some moisture regardless of the moisture content to which it was originally dried. The objective of seasoning then becomes to strike a balance between the conditions of use prevailing in summer and those of winter, so that wood will not shrink unduly in winter nor swell excessively in summer. The temperature and relative humidity in the factory and storage rooms should be such that the desired average moisture condition can be maintained while the products are in the process of manufacture and until ready for shipment. For most parts of the United States, best results in factory fabrication of panels will be obtained where internal framing members have a moisture content of 8 to 10 percent and flooring and interior finish 7 to 9 percent. Precut joist may range from 8 to 13 percent. Factory-processed exterior finish can have a moisture content of 8 to 10 percent, and siding, trim, and other exterior finish applied at the site should have a moisture content of about 11 to 13 percent. In the arid regions of the Southwest, the averages given should be reduced about 2 percent, while in the humid Pacific Northwest and Gulf Coast regions they should be increased about 2 percent.

The moisture content of plywood is determined primarily by the conditions of its manufacture. The so-called mositureproof or exterior types of softwood and hardwood plywoods—those made with hot-setting phenolic glues—range from 2 to 8 percent in moisture content at the time of manufacture. Usually, in storage they pick up some moisture and, depending upon the conditions of their ultimate use in housing, there may be some further gain. The moisture-resistant types, made with protein glues, vary according to whether they were made in hot or cold presses. If hot-pressed, their moisture content is generally below 10 percent; if made in cold presses, their moisture content may range from 10 to 15 percent. The terms moistureproof and moisture-resistant do not mean that the plywood has these properties, but refer only to the possible effects of moisture

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upon the glue holding the veneers together. The principal reason why moisture-resistant types of plywood have a higher moisture content is because of the moisture in the glues used; generally, also, the veneer for moisture-resistant types is not dried to so low a moisture content as is that for the exterior-type plywoods. If made in cold presses, the moisture-resistant types generally have a higher moisture content than if made in hot presses. To maintain the low moisture content of plywood, storage inside a building is usually necessary.

9.1. LUMBER SEASONING.—The two methods of seasoning wood in common use are air seasoning and kiln drying. In most parts of the United States, air drying will in time bring the moisture content of wood to about 14 to 17 percent. With kiln drying, of course, the moisture content can be reduced to whatever point is desired. Since the moisture content desired for prefabricated construction is below that which can be obtained by open-yard air seasoning, best results will be obtained where the stock is kiln dried or where it is stored in heated storage rooms until adequately dried.

9.10. Air Seasoning.—Air seasoning is the oldest and simplest method of drying lumber. It consists of exposure of green lumber outdoors or in sheds. Its effectiveness is limited by the vagaries of weather conditions, which in turn limit both the degree to which the drying rate can be controlled and the final moisture content attainable. As a result, the drying period is relatively long and the final moisture content is dependent on the atmospheric conditions existing at and shortly preceding the end of the seasoning process (*9–4*).

Although general weather conditions are beyond control, certain controllable local conditions affect the atmospheric conditions in the yard, and proper spacing and size of piles and methods of piling can speed the rate of air seasoning materially or, alternatively, retard it to some extent to avoid excessive checking.

9.100. Site.—Lumber that will withstand rapid air seasoning should be piled on high ground that is fairly level, well drained, and not adjacent to water bodies or wind-obstructing objects, such as tall trees or buildings. A yard located in a hollow is sheltered from the full sweep of the winds and the ground is likely to be relatively damp, promoting stain and decay of lumber. The yard should be kept free from vegetation. Cinders make an excellent surface dressing, allowing rain water to seep through readily and restraining the growth of vegetation. Coarse salt or crude oil sprinkled on the ground controls vegetation.

9.101. Layout.—Lumber should be piled in an air seasoning yard in such a way as to form main, rear, and cross alleys and spaces between the sides of the piles (fig. 9–1). The alleys permit hauling of the lumber and, together with the side spaces, allow air to circulate through the yard. Main alleys should be from 16 to 20 feet in width, rear alleys at least 8 feet, cross alleys 60 feet or more, and spaces between piles 4 to 6 feet in width.

FIGURE 9–1.—View of a main alley of a well laid-out yard, showing good piling and a clean ground surface.

9.102. Foundations.—Lumber pile foundations must be firm, durable, and high enough off the ground to allow air that has circulated through the lumber to escape from below the pile. Foundation piers are made of concrete, masonry, pressure-creosoted blocks or posts of any species or untreated heartwood of such durable species as baldcypress, redwood, or the cedars. Concrete or masonry piers should extend into the ground below the frost line. Wood piers may also be set in the ground or may bear on timbers laid on or slightly below the ground surface. Timbers in contact with the ground must be of heartwood of a durable species or pressure-creosoted to avoid a serious decay hazard. The tops of the piers should slope 1 inch per foot of pile length from front to rear, with the rear piers of sufficient height to keep the lumber pile at least 18 inches from the ground. Unless the

piers are set in the ground, they must be diagonally braced.

Stringers and beams rest on the piers (fig. 9–2). The stringers run from front to rear of the pile. Timbers or steel I-beams or rails make satisfactory stringers. Timbers should be about 6 by 8 inches in cross section and if of species that are not decay-resistant, should be pressure-creosoted. The cross beams rest on the stringers and distribute the weight of the pile. Where sticker spacing and pile length are constant, stringers are sometimes dispensed with. A foundation including stringers can be adapted to varying sticker spacing and lumber length

FIGURE 9–2.—Pile foundation showing concrete piers, timber stringers, and beams.

9.103. Piling.—Because different species and thicknesses of lumber dry at different rates, they should be piled separately. Thick stock requires a longer drying period than thin stock and is more likely to check. Moreover, when pieces of different thicknesses are piled in the same layer, the thinner pieces, not being in contact with the stickers, may warp. It is desirable, where practical, to separate stock also on the basis of length and width.

Lumber of random length should be box piled. This method of piling avoids overhanging ends (fig. 9–3). The longer boards should be placed in the outer vertical tiers, and if there is a sufficient number of these boards for additional tiers, such tiers should be uniformly distributed across the width of the pile. As far as possible, the boards in any tier should be of the same length. Ends of adjacent tiers of short boards should be alternately flush with the front and rear of the pile.

Each successive layer of boards is placed so that the front ends project slightly beyond those of the layer beneath. This produces the pitch of the pile, 1 inch per foot of height. The re-

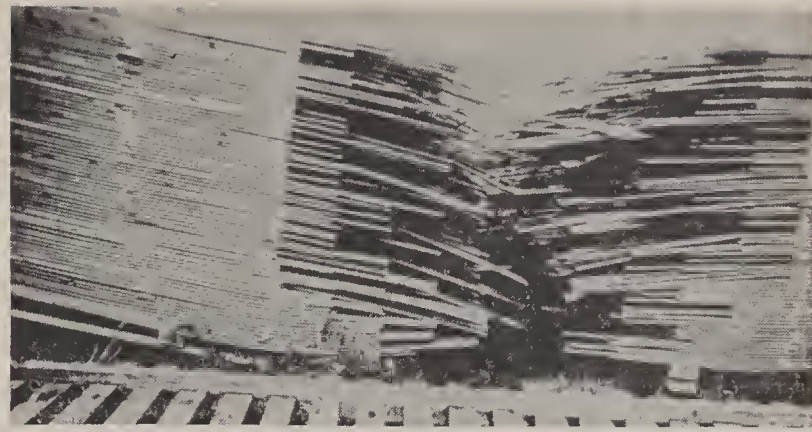

FIGURE 9–3.—Poorly piled lumber with overhanging ends.

sulting overhang helps to keep rain from dripping into the front of the pile. Such overhang is necessary for all sloping piles because, if rain enters the front of such piles, water will flow down the sloping boards and collect where the stickers contact them.

9.104. Stickers.—Stickers are strips or boards used to separate the layers of lumber in a pile. All stickers must be sound, dry, free from stain and decay, and of uniform thickness. Stickers for 1-inch lumber are usually made from nominal 1-inch stock and should not be more than 4 inches in width. The stickers must have sufficient width so that they will not be crushed into the faces of the lumber by the weight of the pile. For softwoods, stickers are usually 4 inches wide. For hardwoods, stickers as narrow as 1½ inches are often used. For lumber thicker than 1½ inches, stickers more than 1 inch thick are used.

Stickers should be placed in good alinement (fig. 9–4) and follow the pitch of the front of the pile, each tier resting on a cross beam. Misalinement of stickers causes warping of the lumber. Stickers are spaced from 2 to 5 feet apart, depending upon the thickness of the lumber and its tendence to warp. Thin stock requires closer sticker spacing than thick stock. Closely spaced stickers tend to hold lumber flat. The tiers of stickers at the front of the pile should protrude beyond the ends of the boards to retard end drying, which in turn reduces end checking.

9.105. Board Spacing, Flues, Chimneys.—Because the principal direction of air movement through a pile is usually downward, ample space must be allowed for this movement. Unobstructed vertical passages extending from top to bottom

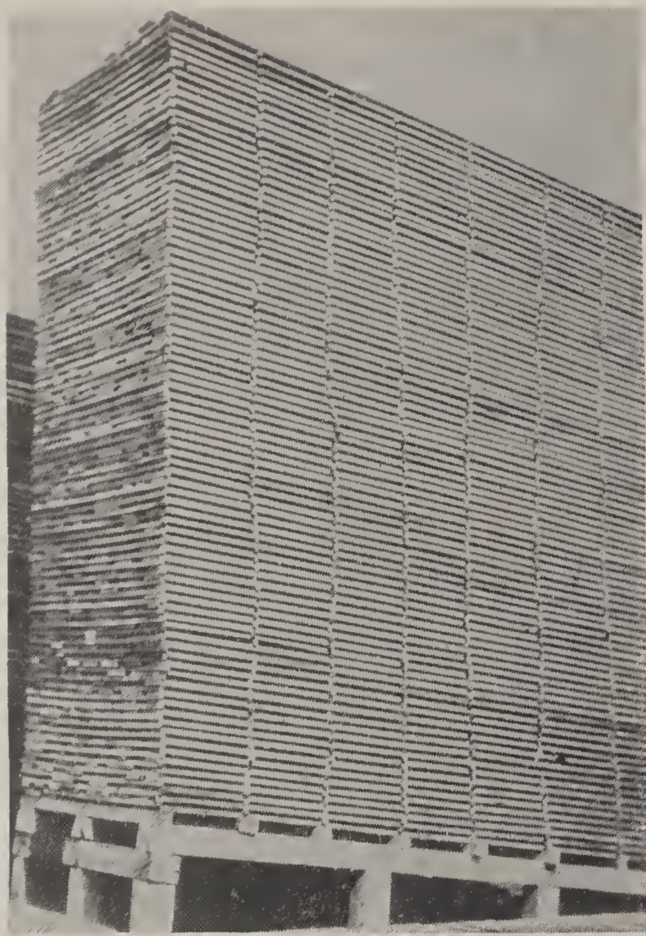

Figure 9–4.—Good sticker alinement but no forward pitch to pile.

of the pile must be provided. The passages are called flues or chimneys, depending on the width. When the width is less than 6 inches, the passage is called a flue; when 6 inches or more, a chimney or vent. The chimney may be either straight-sided or tapered (fig. 9–5) toward the top of the pile. The number, size, character, and arrangement of the flues or chimneys depend on the width of the stock and on the desired speed of drying. Ordinarily, better results are obtained in wide piles if several flues are used rather than a single central chimney.

9.106. Roofs and Sheds.—It is always desirable to protect lumber from snow, rain, and sunshine. Exposure to alternate precipitation and sunshine causes surface checking, warping, and ultimate disintegration of the wood surface. Direct sunshine, by heating the surface of wood and the air next to it, dries the surface too rapidly and induces surface checks. Weather can damage seasoned as well as unseasoned lumber.

Lumber can best be air seasoned in a shed. The shed walls may be tight, slat-sided, or open-sided. Tight sheds must be well ventilated. The roof and walls absorb some solar heat, raising the mean temperature within above that outdoors. If just enough ventilation is provided to get rid of the moisture evaporated from the lumber, the increase in temperature inside will maintain a lower relative humidity than that existing outdoors, thus speeding the drying rate.

If sheds are not available, a temporary roof can be built over the pile to afford protection from direct sunshine, rain, or snow. A tight roof should slope about 1 inch per foot; if it is not tight, it should slope about 1¼ inches per foot, in order to provide satisfactory run-off. The roof should project 1 foot beyond the pile at the front and 2½ feet at the rear (fig. 9–6). The roof must be supported on cross beams, providing a space of at least 5 inches between the roof and the top layer of lumber. The roof should be fastened to the pile by wire or some other means.

Figure 9–5.—A tapered chimney in a yard pile.

The essential features of good piling for rapid air seasoning are summarized in figure 9–7. Such piling is intended mainly for low-grade and easily dried lumber. For stock requiring slower drying, the height of foundation spacing between piles, and the width of the flues should be decreased, while the width of the pile should be increased and thinner stickers (narrow, dry, special stickers are less conducive to checking than stickers taken from the stock being piled) should be used.

FIGURE 9–6.—Pile roofs projecting at front end of pile. (The tramway interferes with air movement around the lower parts of the piles.)

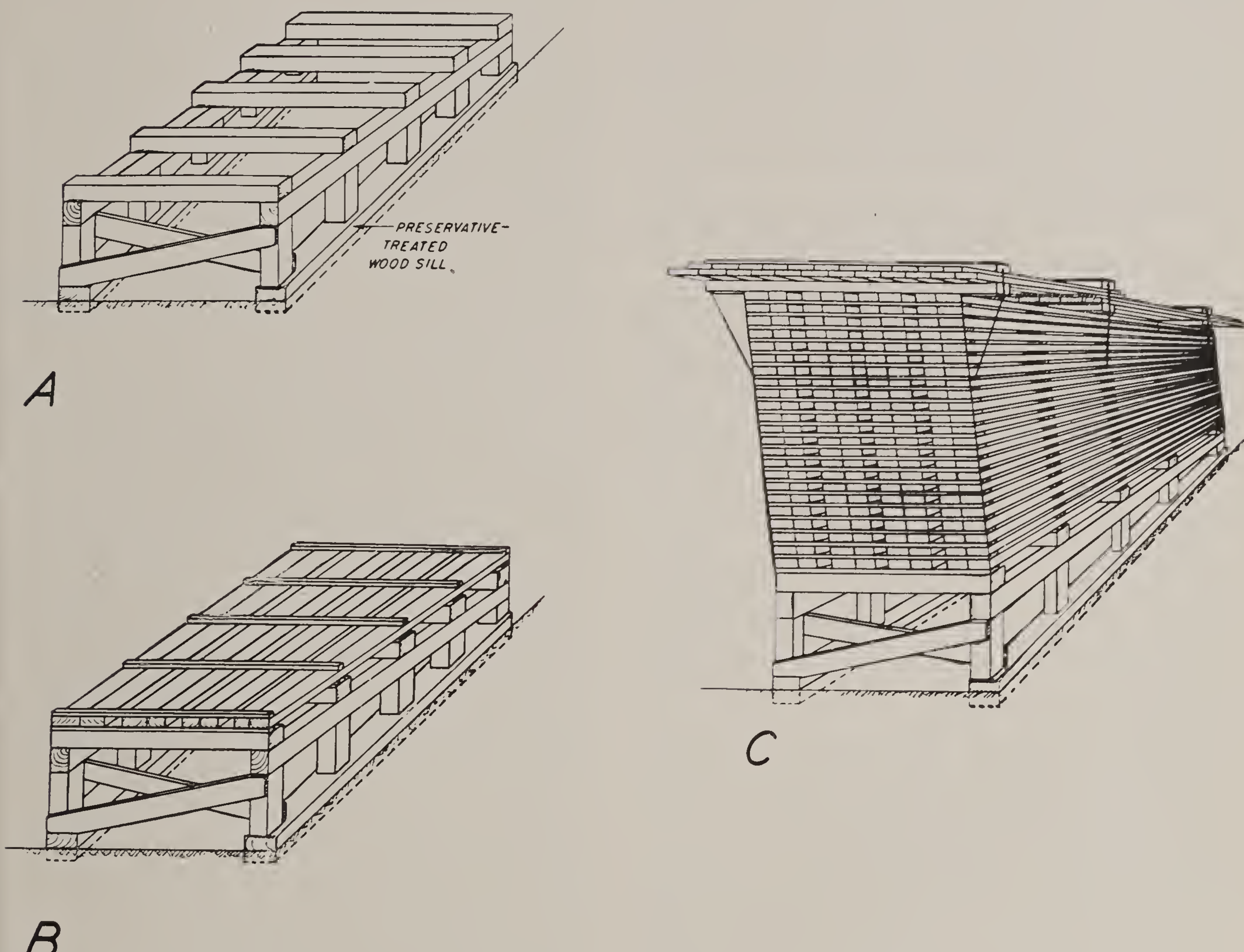

FIGURE 9–7.—Essential features of a good air-seasoning pile of lumber. *A*, foundation for pile, sloping from front to rear 1 inch per foot of length, with rear of pile 18 inches from ground. Ground sills and other foundation timbers of nondurable woods must be pressure treated with a good preservative; otherwise, they may be of untreated heartwood of decay-resistant species. *B*, first tier of lumber in place on foundation, with stickers; total flue width about one-fifth of total pile width, stickers 1 to 1½ inches thick depending on thickness of lumber and spaced not more than 4 feet apart. *C*, completed pile, with temporary roof overlapping pile 18 inches at front; stickers alined above each other to keep lumber flat; roof in two sections to permit use of short boards; upper roof boards centered over joints between lower boards; roof tied to pile with wire.

9.107. End Coatings.—When wood is exposed to atmospheric conditions that cause an appreciable change in its moisture content, areas of end grain should be protected. Water moves through wood more rapidly in a longitudinal direction than it does in the two lateral directions. More moisture is thus lost from a given area of end-grain surface than from the side faces. A thicker dry zone is created thereby at the end-grain surface, because of which end checks and end splits are likely to occur. To avoid excessive drying, end coatings are applied. They are particularly useful in reducing waste of lumber if applied as soon as the lumber is received. End coatings are of greatest value for thick or wide stock and for those species that are prone to end check and are less necessary on thin or narrow stock, or for species that are not so likely to end check.

To be satisfactory for large-scale use, an end coating should have (1) adequate resistance to water movement under all conditions of temperature and relative humidity to which it may be subjected during the drying of the wood; (2) ease of application; (3) sufficient toughness and adhesiveness to withstand rough handling and to prevent blistering and cracking during kiln drying; (4) freedom from abrasive substances that may be injurious to saws or cutters during machining of wood; and (5) low cost to cover a given area.

End coatings may be liquid at ordinary temperatures and applied without being heated or solid at ordinary temperatures and requiring heat for application. Hot coatings are well suited for use on small stock that can be easily handled.

The two best cold coatings tested at the Forest Products Laboratory are phenolic-resin varnish pigmented with aluminum paste or powder, and filled hardened gloss oil. Aluminum paste or powder can be dispersed in a variety of vehicles to form water-resistant paints. Even with the most water-resistant vehicles, such as phenolic-resin tung-oil varnish, two coats are required to form a highly water-resistant end coating. About 2 to 2½ pounds of aluminum should be used per gallon of vehicle. Aluminum paints should be mixed immediately before use, because the desirable leafing property of the aluminum particles diminishes as the paint stands in the mixed condition. Aluminum coatings do not cause serious abrasion of cutting tools. End coatings containing aluminum are expensive.

The filled hardened gloss oil developed by the Forest Products Laboratory is made by mixing 25 parts (by weight) of barytes and 25 parts of magnesium silicate with 100 parts of a hardened gloss oil made according to the following formula:

Rosin	100 parts by weight
Hydrated lime	6 to 8 parts by weight
Mineral spirits	57.5 parts by weight

The hardened gloss oil should be made up by a varnish manufacturer because of the technical operations involved. When freshly made, two coats of filled hardened gloss oil assure a highly effective end coating. If desired, some of the solvent may be evaporated, after the pigments are mixed with the gloss oil, to obtain a thickened mixture that will give satisfactory results under many drying conditions when applied in a single coat. When thus thickened, the mixture is somewhat difficult to apply. Large quantities should not be mixed at a time, for eventually the settling of the pigment and loss of solvent combine to make a coating unfit for further use. The filler contained in this coating is slightly abrasive to cutting tools. Filled hardened gloss oil is moderate in cost.

A heavy paste containing a pigment such as white lead in a vehicle such as linseed oil makes a simple coating that is moderately effective when applied in a single coat. The paste should be prepared with only enough oil to allow its application with a trowel or stiff brush. This type of coating is generally available and admirably suited for use in drying small lots of material. Ordinary paints and varnishes are too thin to be effective as end coatings, although they are helpful if several coats are applied. A paint consisting of red iron oxide mixed with a vehicle consisting of a mixture of 75 percent linseed oil, 15 percent nonreactive spar varnish, and 10 percent combined drier and thinner is in common use. There are also numerous proprietary end coatings on the market.

The effectiveness of an end coating depends as much on its thickness as on the material of which it consists. For all coatings, with the exception of the pastes, it is necessary for best

results to apply two or three coats, allowing each to dry before the application of the next.

9.11. Kiln Drying.—In kiln drying the same principles are employed as in air seasoning (*9–5*). Kiln drying is accomplished at higher temperatures than is air seasoning, but in modern, efficient dry kilns the drying conditions are at all times under control, so that they may be suited to the requirements of the lumber. It is possible to hasten or retard drying and to obtain a predetermined final moisture content. In general, lumber up to 2 or 3 inches in thickness can be dried in a shorter period and with fewer drying defects in a kiln than by air seasoning. Somewhat thicker lumber can be kiln dried by the use of special schedules but, in general, the kiln drying of heavy material is impractical because of the development of defects and the length of time required.

9.110. Dry Kilns.—A dry kiln is essentially an enclosure or building provided with suitable apparatus for the control of temperature, humidity, and air circulation, within which lumber can be piled and dried to the desired moisture content. Lumber is piled on trucks and wheeled into and out of the kiln. Heat is usually provided by piping live or exhaust steam through coils or radiators, but may be provided by a furnace or smoke pipe; some small kilns are heated with electricity. The air within the kiln is generally humidified by steam sprays. Air is circulated through the kiln and the lumber piles by gravity or by mechanical means, such as internal fans or external blowers. The temperature and relative humidity may be controlled by manipulating the heating and steam spray valves and vents, or by instruments that automatically control temperature and relative humidity.

9.1100. Types of Kilns.—Dry kilns for wood are of many forms and types. On the basis of construction and operation, they can be divided into two groups, progressive and compartment (sometimes called "box" or "charge" kilns).

In a progressive kiln, a number of truckloads of lumber at different stages of drying extend through the kiln in an unbroken line. Truckloads of green stock are periodically fed into the kiln and truckloads of dried stock removed at the same time from the other end of the line. The stock thus moves progressively through the kiln until it emerges, supposedly dry, after a specified time of exposure to the various conditions along the length of the kiln. The temperature and relative humidity at any point are intended to remain constant, but the kiln is hotter and drier at the dry end than at the green end.

The compartment kiln is loaded fully at one time, the entire charge remaining in place throughout the drying period. The temperature and relative humidity are as nearly uniform as possible along the length of the kiln, especially on the entering-air side, at any given time.

The field of a progressive kiln is limited, whereas a compartment kiln can be used for any kind of drying. A progressive kiln must be supplied continually with lumber of a single kind and thickness to function properly and, therefore, is not satisfactory except where a constant supply of such stock is available. Progressive kilns are used to dry easily dried softwoods, such as southern yellow pine and Douglas-fir, or air-seasoned hardwoods.

Kilns may also be classified on the basis of the means used to obtain circulation. In natural-circulation kilns, air heated by the steam coils rises through the flues or chimneys in the lumber piles, some of it leaving the kiln through the chimney and causing fresh air to enter through the inlet ducts. Moist air is thus removed and replaced by drier air, reducing the relative humidity within the kiln. The drying of the lumber is accomplished chiefly by the recirculation of air past the steam coils and through the lumber pile, cooling as it rises and dropping when cooled sufficiently. This type of circulation is slow but is well distributed through the lumber pile if suitable chimneys and flues are built into the pile and the air is correctly baffled. Natural-circulation kilns are adapted to the drying of most lumber except the green lumber of most hardwoods. Steam sprays or jets are used in natural-circulation systems, being placed so that the impact of the spray helps the natural air movement.

Forced-circulation kilns usually produce air movement with internal fans or external blowers. These kilns are equipped with air intakes and ventilators. The internal fans force the air into a space from which it must pass laterally through the lumber pile in order to return to the fans. The external blower forces air into a duct, supplied with openings, which extends

the length of the kiln. After passing out of the openings the air travels through the lumber pile. Some of the moist air then leaves the kiln through ventilators, but most is directed back to the blower through return ducts. Forced-circulation kilns accomplish more rapid drying and maintain more nearly uniform conditions on the entering-air side of the kiln than do natural-circulation kilns. They are therefore well suited to the drying of lumber for housing.

9.111. Piling of Lumber.—Lumber is piled in a dry kiln in such a manner that surfaces are exposed to the currents of moving air. This requires that the boards be separated by stickers, as in air seasoning. For most designs, the stickers are placed parallel to the direction of air movement. In natural-circulation kilns, where vertical movement of the air is strongly relied on, vertical flues at least 4 inches wide and spaced 12 to 14 inches apart must be provided. In forced-circulation kilns, with lateral circulation, the boards may be piled edge to edge. In some designs a central chimney is utilized. When material is nearly square in cross section, spaces are usually left between the edges to obtain some edge drying.

9.112. Drying Schedules.—In kiln drying, wood is exposed gradually to higher temperatures and lower relative humidities until the desired moisture content is attained. The series of steps of temperature and relative humidity used to dry a kiln charge of lumber is termed a drying schedule. Woods differing in species, thickness, character of grain, and moisture content require different drying conditions or schedules; thus, Douglas-fir joists will require a different schedule than 1-inch ponderosa pine finish. The Forest Products Laboratory has prepared kiln-drying schedules for most native United States species. These schedules, especially for hardwoods, are not based on time but on the moisture content of the lumber, and therefore require the use of kiln samples for proper operation. The conditions of the first step in the appropriate schedule should be established as quickly as possible. The steam sprays should be used to help in heating the kiln and in maintaining a high relative humidity during the time when the kiln and lumber are being heated, but in no case is a long initial steaming period recommended. A long initial steaming treatment is particularly detrimental when the charge consists of surface-checked air-seasoned lumber.

9.12. Seasoning Defects.—Shrinkage causes most of the defects that develop during seasoning.

9.120. Surface Checks.—A surface check occurs on the face or edge of a board or timber. It is a lengthwise separation of the wood, the greater part of which occurs across the rings of annual growth. A surface check usually originates at a point where there is a natural break in the continuity of the wood fibers, such as a knot, a resin duct in some softwoods, or a ray in hardwoods. It is a tensile failure across the grain caused by drying and shrinking of the surface zones while the interior is still at a relatively high moisture content and unshrunken. Surface checks are confined to flat-grain faces and are usually more common on the side of the piece that was nearest the bark when in the tree. Wide stock surface checks more readily than narrow stock and thick stock more readily than thin stock. Boxed-heart timbers, which have four flat-sawed faces, often develop surface checks on all faces. These checks may penetrate deeply into the timber, even to the pith.

9.121. End Checks.—End checks belong in the same category as surface checks, but they originate on end-grain surfaces. They start as separations of the wood fibers extending across the rings of annual growth and soon turn into a lengthwise separation of the wood as they progress inward. Because of rapid drying from the end grain and the exposure of the ends of the wood fibers, end checks form more quickly than do surface checks. End checks are responsible for much waste of material because, for many purposes, the ends must be trimmed off until the end checks are eliminated.

9.122. Splits.—A seasoning split results when an end check and a surface check meet. A split is usually more serious than an end check or a surface check, because it is likely to extend farther along the face and deeper into the piece. In boards, splits often extend from face to face.

9.123. Warp.—When a board or timber becomes distorted so that its faces are no longer true planes, it is said to be warped. Warp includes bow, crook, cup, and twist. Distortion of a board so that its faces are convex or concave

longitudinally is called bow; distortion of the edges of a board so that they are convex or concave longitudinally is called crook; distortion of a board so that its faces are convex or concave transversely is called cup; and distortion of a board by turning or winding the edges so that the four corners of any face are no longer in the same plane is called twist.

Warp is more common in stock of small dimension than in heavy stock. It is caused by natural shrinkage differences in the different directions of grain. Such differences may be present in the two faces of a flat-sawed board, and are marked in boards containing distorted grain such as is caused by knots and cross grain. Warp is also caused by differences in shrinkage between normal wood and such abnormalities as compression wood. Uneven drying also causes boards to warp. Projecting board ends, insufficient stickering, and poor vertical sticker alinement in drying piles contribute to warp. Most warping takes place during seasoning, but a board may warp after it has been seasoned if it is exposed to alternately wet and dry conditions.

9.124. Honeycomb.—Honeycomb checks are checks that occur in the interior of a piece, usually along the rays. They may be the result of an extension of an end or surface check. Like end and surface checks, they are the result of failure of the wood in tension across the grain. They occur during the later stages of drying, when the interior is losing moisture and shrinking under restraint. Honeycomb is more prevalent in thick stock, hardwoods, and kiln-dried stock than in thin lumber, softwoods, and air-seasoned lumber. Excessively high initial kiln temperatures contributes to the formation of honeycomb checks. Honeycombing often can be detected by the appearance on the surfaces of grooves running along the length of the piece.

9.125. Case-hardening.—The term "case-hardening" as applied to lumber is often misunderstood and confused with the meaning as applied to metals. Case-hardening as applied to wood does not mean that the surface is hardened, but denotes a stressed condition present in dry lumber; namely, compression on the surfaces and tension in the interior. This condition is brought about by the fact that the various zones of the wood have dried under different degrees of restraint and have become "set." The differences in set between the various zones cause the stressed condition in the dry lumber.

Although case-hardening exists when the wood is dry and the moisture is uniformly distributed throughout the piece, those factors that cause the final condition are at work throughout the entire drying process. Because of the manner in which wood dries, some degree of set is unavoidable. This set, however, can be removed near the end of the drying period by conditioning treatments. It is possible, therefore, to kiln dry lumber without causing serious case-hardening in the dried stock.

9.126. Collapse.—Collapse is the flattening of single cells or rows of cells, usually in the heartwood, during drying of wood or pressure treatment with preservatives. The cell walls come together, practically eliminating the cell cavity. Collapsed portions have abnormally large shrinkage, which is manifested by a corrugated appearance of the faces of a board. Collapse is common in the heartwood of those woods through which moisture moves slowly and whose moisture content when green is unusually high, such as lowland oak, redwood, and Western redcedar. The exact causes of collapse are not known, but it may be caused by liquid tensile forces exerted in cells completely full of water or by compressive stresses developed during drying. Collapse is often associated with honeycombing and, as in honeycombing, high initial drying temperatures contribute to its formation.

9.2. HANDLING AND STORING HOUSING MATERIALS.

9.20. General.—The use of well-seasoned lumber, plywood, and other forms of wood in the manufacture of prefabricated houses requires that these materials will be kept in a suitably dry state during manufacture and assembly into the finished house. In the course of manufacture, the materials that go into the house are handled frequently; and, necessarily, there must be some storage of materials and finished parts somewhere along the line between manufacture and the construction of the house.

"Handling" of lumber and other materials refers to the various steps in manufacture and the intervals between steps when the materials are not more or less permanently piled for storage. For example, lumber may be unloaded from a freight car or truck for a few days

before being moved into the storage sheds; or milled pieces, such as framing components of panels, may be molded or otherwise machined weeks in advance of their final assembly on the panel jigs.

By storage is meant the warehousing of materials and parts for relatively long periods—several weeks or months. Under normal conditions, many prefabricators keep several months' supply of lumber and plywood on hand.

In all handling and storage, one of the most vital points is to maintain the material in the most desirable state of dryness. Unless the proper steps are taken, the prefabricator may find that his materials have gained or lost considerable moisture in the course of storage and manufacture—moisture that can cause serious losses in the form of warping, checking, splitting, and similar degrade. Improperly stored finished panels and other parts, likewise, can be critically affected by changes in moisture content and prove unsuitable for use because of delaminated glue joints, splits, and warpage that render them difficult if not impossible to assemble at the factory or at the building site.

9.21. Factors Affecting Storage and Handling.

9.210. Moisture Content of Lumber.—The first requirement in assuring that dry lumber, and only dry lumber, will be used in manufacture of house parts is to spot check each shipment as it arrives at the plant. Such a spot check can be made with a reliable moisture meter (sec. 3.61). The thoroughness with which such a check is made depends upon (1) the source of material, (2) species of wood received, and (3) the uniformity of moisture content as indicated by results of the first random check tests. Where lumber is received from a steady, reliable source and consists of uniformly graded stock of a single species, perhaps only four or five boards in 4,000 to 5,000 board feet need be tested to give assurance that the lumber is uniformly dried. Where lumber is bought from various mills, shipments consist of different

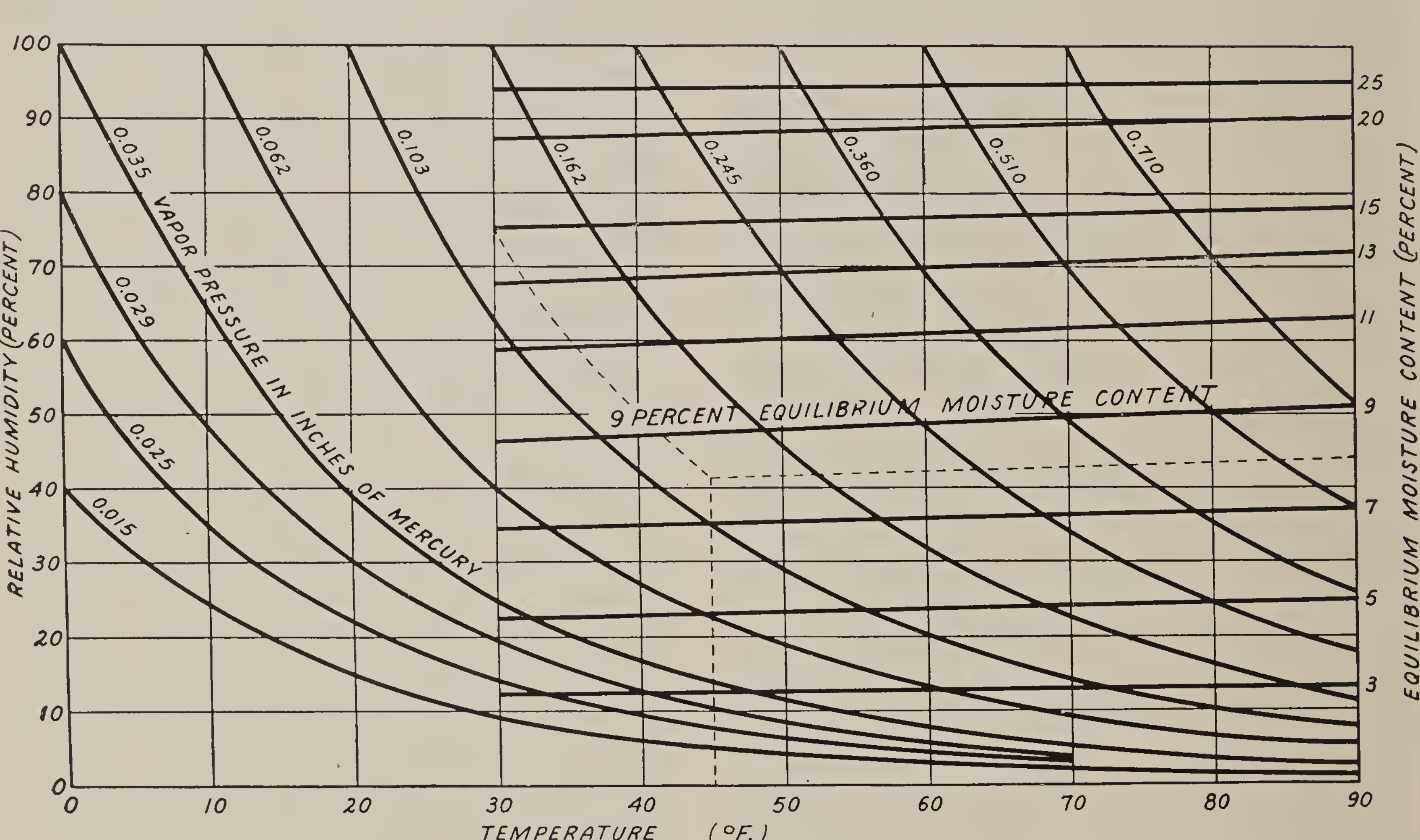

FIGURE 9–8.—Equilibrium moisture content curves for wood. Example: To determine what temperature should be maintained when the outdoor temperature is 30° F., the relative humidity 80 percent, and the desired equilibrium moisture content 8 percent, proceed as follows: From the intersection of the (vertical) 30° temperature line and the (horizontal) 80 percent relative humidity line, extend a line midway between the adjacent (concave) vapor-pressure lines until it intersects a line midway between the 7 and 9 percent moisture content lines indicated in the right-hand ordinate. The reading on the bottom scale at the point of the second intersection is about 47° F.

species, or experience has shown that the moisture content tends to vary considerably, more thorough check should be made.

The purpose of such a spot check is to determine whether the lumber as received requires further drying. If the check indicates that it does, and additional meter tests confirm this, such drying can usually be done in heated storage rooms if dry kilns are unavailable.

9.2100. Drying Partially Seasoned Lumber.—The final drying of partially seasoned lumber to a moisture content of 10 to 12 percent usually requires the use of artificial heat (*9–2*). Such drying can most conveniently be done in a storage room heated with unit heaters or heating coils. The temperature and relative humidity required to attain and maintain a desired moisture content can readily be determined from the curves in figure 9–8.

To hasten the final drying process, the relative humidity may be 15 percent below that required to maintain the final desired moisture content. For example, assume that lumber at a moisture content of 30 percent is open piled in a heated room and is to be dried to 10 percent. Figure 9–8 shows that, at 90° F. and 58 percent relative humidity, the equilibrium moisture content is about 10 percent. The relative humidity in the storage room should then be maintained at about 43 percent (58 minus 15 percent).

The lumber should be piled in the room in the same manner as for air seasoning (sec. 9.1) except that pitch and slope of the piles are not required, the spacing between piles may be reduced to 2 feet, and the piles should be not more than 6 feet wide. The space between piles and walls should be not less than 2 feet to permit good circulation of air. Lumber should be piled so that the air can circulate freely down through the piles. Further, heating coils or unit heaters should be so placed that the lumber is protected from direct radiant heat of coils or from the high-velocity air streams of the unit heaters. When the heat is supplied by coils, fans may be used as necessary to stimulate air movement sufficiently to keep temperatures reasonably uniform.

The services of a competent heating and ventilating engineer will probably prove useful in designing heated storage rooms that will fulfill their function at minimum operating cost.

Moisture meters (sec. 3.611) or the oven-drying method of determining moisture content (sec. 3.610) can be used to determine whether the lumber has been dried sufficiently after a period of seasoning in the storage room. This test can be employed with boards selected at random from the pile (at least 5 boards selected at random should be tested for each pile).

9.2101. Storage of Dry Lumber.—The method employed to store dry lumber is governed by the use to which the lumber is to be put. Lumber that is to be exposed to outdoor conditions when installed in the house may safely be solid piled in open sheds provided that the prevailing conditions of humidity at the plant will be similar to those prevailing at the building site. Usually they are; most prefabricators limit their shipments to a maximum of 200 to 300 miles.

Lumber that is to be used for framing members of panels or sections and lumber that will be installed inside the house as millwork should, however, be stored in heated rooms, especially during the fall and winter (*9–3*). The term "heated room" in this case requires definition; the heat actually supplied may be comparatively little. The amount of heat required depends not upon accepted standards of human comfort but upon the law of physics which governs the effect on moisture content of the temperature and relative humidity of the atmosphere.

To illustrate this relationship of temperature and relative humidity to moisture content of wood, assume that lumber dried to 7 percent moisture content is sticker piled in an unheated room. Under these conditions, the lumber will increase in moisture content by an amount depending upon the temperature and relative humidity of the air, as indicated in figure 9–8. At a temperature of 30° F. and 75 percent relative humidity, the lumber will increase in time to a uniform moisture content of about 15 percent. Figure 9–8 shows also, however, that if the air could be heated to 45° F., the relative humidity would be reduced to 41 percent and the moisture content of the lumber at this temperature would not rise above 8 percent. Raising the temperature to 50° F. would keep the lumber at 7 percent. Thus, only a relatively small amount of heat is required to maintain the lumber at this low moisture content, and the room may be kept actually colder than the

main plant during some seasons. Under the stated conditions, it is not necessary, if the room is heated to 50° F., to sticker pile the lumber; solid piling would be satisfactory. On the other hand, if the room were entirely without heat, solid piling would cause exposed ends and faces of lumber to gain moisture, and such boards, when subsequently exposed to ordinary heated room conditions, may shrink and check objectionably.

Construction and equipment of heated storage rooms should be done on the advice of a competent heating and ventilating engineer. Where steam is available for heating purposes, coils or unit heaters serve satisfactorily; some storage rooms are heated with electric space heaters. Irrespective of the kind of heater used, care should be taken that the lumber be protected from radiant heat or high-velocity heated air streams.

Automatic control of heated storage rooms can be effected with hygrostats that turn the heat off or on with changes in temperature and relative humidity of the atmosphere. Hygrostats can be regulated with reasonable exactness if a number of pieces of resin-free clear sapwood of known oven-dry weight are placed at the center and ends at several elevations in the room and their weights checked once or twice daily so that variations in equilibrium moisture content conditions can be kept under close observation. The sample pieces used for such checks should not be oven-dried, however, as they will not function properly. Instead, their oven-dry weight can be calculated by determining the oven-dry weight of adjacent strips of the same size cut from the same piece of wood. A convenient oven-dry weight is 100 grams; with each 1-gram change in weight a 100-gram strip will register a fluctuation of 1 percent in its moisture content—an indication that more or less heat is required to maintain constant equilibrium moisture content conditions in the room. The hygrostats can be adjusted as necessary.

Where a large shed is available for heated storage, it is perhaps advisable to divide it into smaller sections conveniently laid out for loading and unloading. Such a division will make it possible to open one section without disturbing conditions in the others.

9.211. Plywood Storage.—The low moisture content at which most plywood is manufactured makes it necessary to store it in heated storage rooms such as that described in section 9.2101. Many prefabricators have experienced difficulty with plywood stored for any length of time in open sheds or rooms in which heat and relative humidity are not properly controlled. Solid-piled plywood tends to absorb moisture along the exposed edges of each sheet, and these tend to swell while the protected parts of the sheet remain dry. The cumulative result of this end-grain absorption of moisture in a high pile is that the upper sheets tend to develop a pronounced concave shape rendering them troublesome when assembled into panels or sections. Subsequent shrinkage of the edges may cause sunken joints and other defects in appearance.

Such swelling of edges can be avoided by storage in a heated room controlled as described in section 9.2101. If the moisture content of an incoming shipment is considered to be too low for use in housing, the plywood should be piled with one-half-inch stickers so that air can be circulated across the surfaces of each sheet, thereby gradually increasing its moisture content. Such changes can be controlled to a certain degree by storage in a heated room, although some means of humidification may prove necessary to increase the relative humidity of the atmosphere.

9.212. Factory Conditions.—An important, but frequently ignored, problem in the handling of lumber and plywood at various points in the prefabrication process is the control of its moisture content. As lumber moves from storage through the different steps in manufacture of house parts, it may be exposed to temperature and relative humidity conditions adversely affecting its dimensional stability. For example, framing may be sawed to length, dadoed, and molded, then piled for several days before being assembled into panels. Even though under roof in a completely enclosed shop, these machined members may change appreciably in dimension during the period of storage preceding their assembly on the jigs. As a result, gluing surfaces will be uneven at joints between members, grooves for fiberboard insulation and fittings may prove too small, and other difficulties ascribable to dimensional change may appear.

Some manufacturers attempt to circumvent such troubles by operating their machines and

assembly schedules on a day-to-day basis. Thus, framing members of panels are machined the same day they are assembled into the finished panel. Such close scheduling of cutting and assembly operations is not always feasible, however, and production can be seriously interrupted if, for example, a machine breaks down.

Where there is a lag of more than a day or two between the various production operations, it is advisable to store machined parts and semi-finished material in heated storage rooms similar to that described in section 9.2101. It is possible that two or more such rooms may be needed at strategic points along the production line, especially in fall and winter in most parts of the United States.

9.213. Shipment of House Parts.—The shipment of prefabricated house parts is, under normal conditions, not seriously encumbered with difficulties due to shrinkage and swelling. Ordinary protection afforded by enclosed trucks or freight cars is sufficient to prevent important changes in moisture content even for transcontinental shipment.

Where the distance is short and good weather is assured, probably no more than a tarpaulin over the load is needed to protect the parts from possible rain. Prefabricators who ship their house sections or panels distances sufficient to involve weather risks, however, usually either crate them (fig. 9–9) or use completely enclosed trailer trucks or railroad boxcars (fig. 9–10). For even long freight hauls, however, studies have shown that the change in moisture content of lumber shipped in tight boxcars is so small as to be inconsequential (*9–1*). If trouble with dimensional changes is experienced, therefore, the cause probably lies in the conveyance used, which may require repair of a leaky roof or other construction fault. Packing precautions such as crating and blocking to protect parts from damage during shipment are generally more necessary than special protection from moisture (sec. 14.7).

9.214. Protection at Site.—Many prefabricators schedule assembly operations so that the floor is laid one day, followed by erection of walls and roof the next (sec. 14.8). By so doing, the risk of damage by rain and snow is held to a mini-

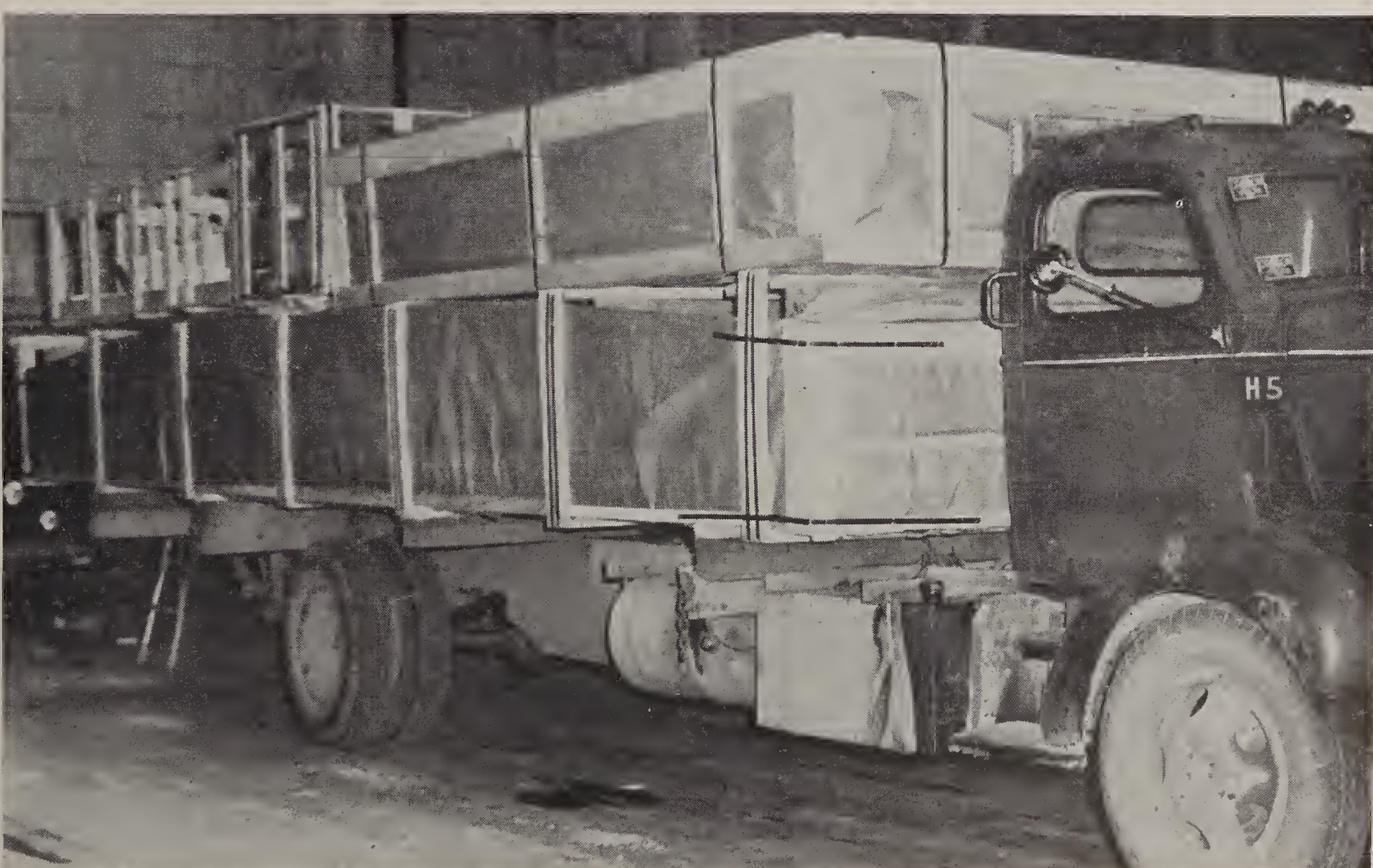

FIGURE 9–9.—Sections of prefabricated house crated for open truck shipment.

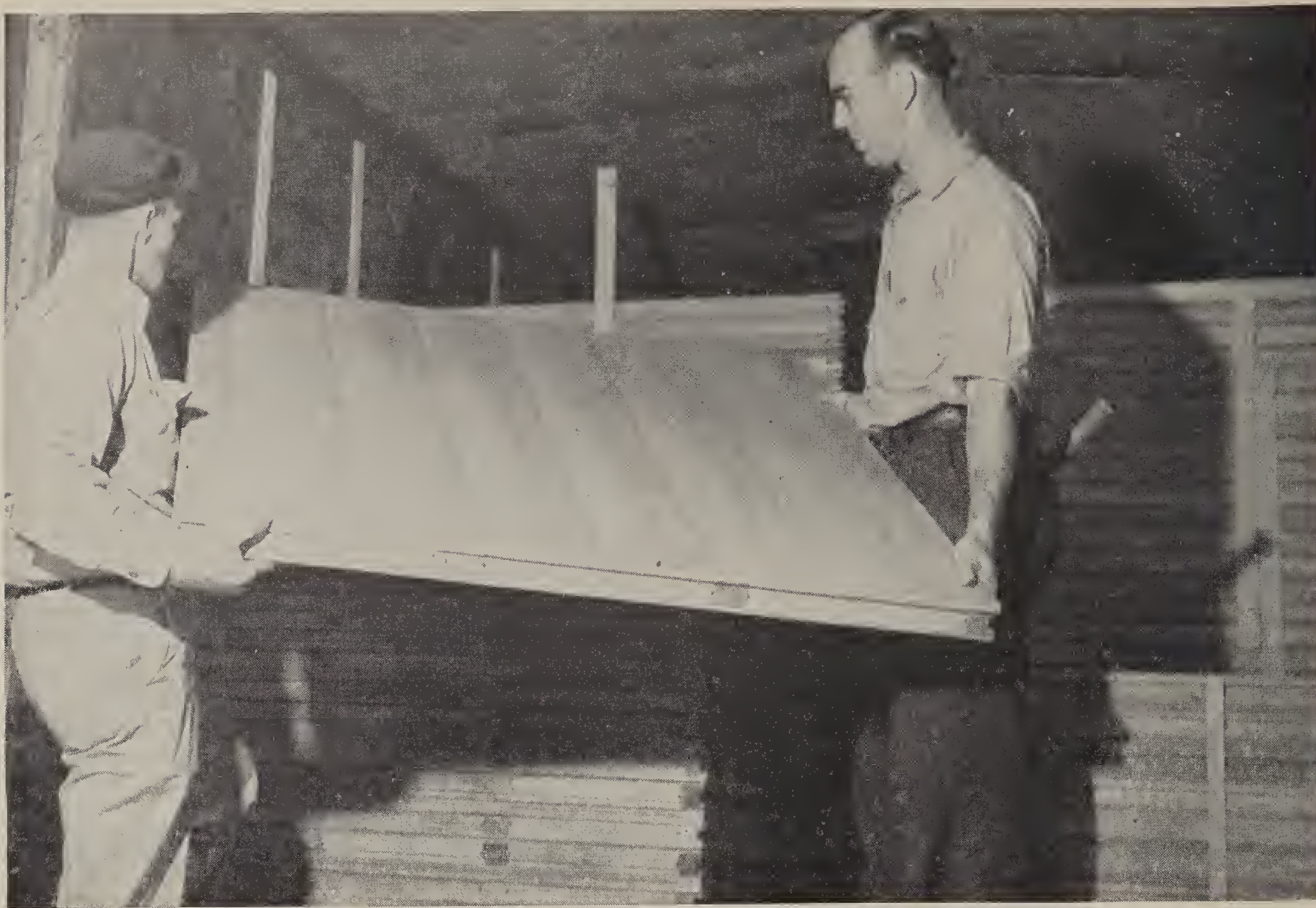

FIGURE 9-10.—Packing house panels in a railroad boxcar.

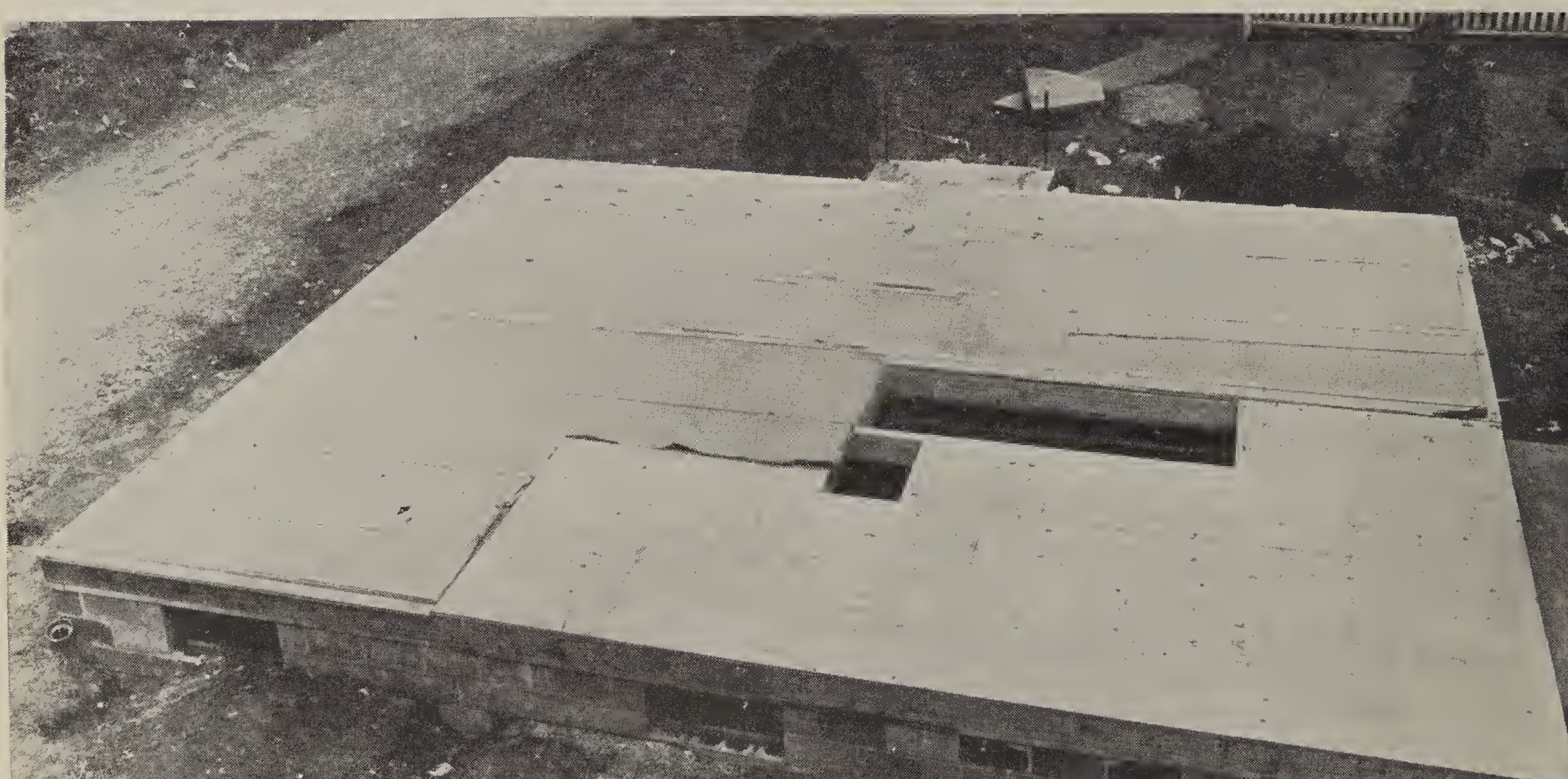

FIGURE 9-11.—Floor of prefabricated house laid with heavy building paper for protection during erection of superstructure.

mum. Delivery of parts is scheduled to coincide as closely as possible with the time of erection, usually the previous day or night. Where shipment is by truck direct from the factory, such close scheduling is feasible. It is nevertheless a good practice to cover the floor with a heavy building paper, which can be left in place until the superstructure has been erected to furnish protection during construction (fig. 9–11). If delivery of parts is made the day before, the practice of parking the trailer overnight at the building site is preferable to that of unloading the panels and other parts on the ground and leaving them exposed to the elements. If it is necessary to pile the panels in the open, they should be covered with a tarpaulin and supported at least 1 foot above the ground by means of blocking or rough scaffolding. While there is virtually no risk of overnight dimensional change during dry weather, precautions against overnight weather changes that may delay erection for an indefinite time are advisable.

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MACHINING OF WOOD AND OTHER HOUSING MATERIALS

10.0. GENERAL.—Among the important classes of properties that affect the utility of any housing material are its machining properties. This is true for wood and wood-base materials, including plywood, laminated wood, densified wood, fiberboards, and sandwich constructions, although most of these are relatively easy to saw, plane, and shape. The standard woodworking tools are, with comparatively few exceptions, suitable for working these materials, although the compressed woods and some sandwich materials, notably those made with metal or other dense faces, require special saws and knives.

10.1. MACHINING PROPERTIES OF WOOD.—Machining properties relate to the behavior of a wood when planed, shaped, turned, or put through any of the standard woodworking operations. For some purposes, the difference between woods in machinability is negligible, but for others the smoothness and facility with which they can be worked may be the most important of all properties, because unless a wood machines fairly well and with moderate ease it is not economically available regardless of its other virtues. Thus, along with specific gravity and the tendency toward splitting and warping, machinability is of the first importance to the worker.

Unlike the physical, chemical, and mechanical properties, machining properties of wood have had little systematic study. There has, of course, been a wide body of experience built up by craftsmen in saw and planing mills, furniture and millwork factories, and other wood-using industries. The builder of prefabricated houses can, directly or indirectly, get the benefit of such experience when purchasing softwood lumber, which is usually machined at the source and is as a rule easy to machine with standard woodworking equipment. The mills supplying him can, furthermore, usually furnish needed data on the planing and other characteristics of the woods purchased.

With hardwoods, this is less frequently the case. Moreover, hardwoods are as a rule not so easy to work as are softwoods. Many of them are heavier and more dense, and possess other characteristics that cause machining difficulties. It is for these reasons that the Forest Products Laboratory has concentrated its machining studies upon the hardwoods. A brief digest of some of the pertinent results of these studies is presented in this chapter (*10–1*). The principal machining operations studied were planing, shaping, turning, boring, mortising, and sanding. Certain physical properties of wood, such as specific gravity, moisture content, tendency to split when nailed or screwed, together with the number of annual rings per inch and the amount of cross grain, shrinkage, and warp, were taken into consideration in these studies. Comparative machining properties of a number of hardwoods are given in table 10–1.

10.10. Planing.—Planing is the most important of the machining operations, since nearly all hardwood lumber is planed before use. In addition to the factors that affect all machining operations, such as species, specific gravity, and moisture content, planing is affected by many different adjustments of the machine itself, making it probably the most complex of woodworking operations. Jointers are similar in action to planers, and results obtained in planing of wood will in general be found to apply to jointing properties.

In the Forest Products Laboratory studies, 19 native hardwoods, including those most commonly used, were planed at cutting angles of 5°, 10°, 15°, 20°, 25°, and 30°, and with two combinations of cutter-head speed and rate of feed: 3,600 r.p.m. at 36 feet per minute, and 5,400 r.p.m. at 54 feet per minute.

Table 10–2 shows the percentage of defect-free pieces of each species tested obtained at the various cutting angles, while table 10–3 shows the percentage of defect-free pieces of each obtained at the two combinations of cutter-head speed and rate of feed. Of the many factors af-

TABLE 10-1.—*Some machining and related properties of hardwoods*

Kind of wood	Planing—Perfect pieces	Shaping—Good to excellent pieces	Turning—Good to excellent pieces	Boring—Good to excellent pieces	Mortising—Fair to excellent pieces	Sanding—Good to excellent pieces	Steam bending—Unbroken pieces	Nail splitting—Pieces free from complete splits	Screw splitting—Pieces free from complete splits
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
sh	75	51	79	94	62	75	67	65	71
asswood	64	9	68	75	51	17	2	79	68
eech	—	21	90	99	93	49	75	42	58
irch	63	53	80	98	97	34	72	32	48
hestnut	74	24	87	91	72	64	56	66	60
ottonwood	21	3	70	70	52	19	44	82	78
lm	33	11	65	94	75	66	74	80	74
ackberry	74	10	77	99	70	—	94	63	63
[aple, hard	54	62	82	99	95	38	57	27	52
[aple, soft	41	22	76	80	36	37	59	58	61
ak, chestnut	—	23	90	100	100	75	85	49	70
ak, red	91	21	84	99	100	81	86	66	78
ak, white	87	28	85	95	100	83	91	69	74
veetgum	51	21	86	92	58	23	67	69	69
/camore	22	8	85	98	96	21	29	79	74
upelo, black	48	23	75	82	24	21	42	65	63
upelo, water	—	43	79	62	35	34	46	64	63
alnut, black	62	34	91	100	98	—	78	50	59
illow	52	5	58	71	24	24	73	89	62
ellow-poplar	70	12	81	87	63	19	58	77	67
Average	58	24	79	89	70	43	63	64	66

TABLE 10-2.—*Planing: Effect of cutting angle on quality of work* [1]

Kind of wood	Defect-free pieces at cutting angle of—					
	5°	10°	15°	20°	25°	30°
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
h	69	70	72	73	79	53
ısswood	—	—	52	65	68	65
rch	—	—	71	63	55	—
ıestnut	—	—	81	76	65	34
ıttonwood	40	37	25	27	12	31
m, soft	24	24	48	33	19	18
ıckberry	37	47	75	93	54	20
ıgnolia	87	78	78	56	62	61
ıple, hard	—	—	56	56	51	17
ıple, soft	43	61	57	33	34	18
k, red	66	96	95	92	87	65
k, white	74	98	95	93	74	37
eetgum	35	66	54	51	49	44
camore	25	39	26	23	18	18
pelo, black	42	52	47	53	43	37
ılnut, black	—	—	64	73	50	—
llow	32	46	50	59	46	10
llow-poplar	66	75	75	67	67	48

[1] For each cutting angle shown the test pieces were planed under two different conditions: (1) At 36 feet per minute feed and 3,600 r.p.m. and (2) on osite side at 54 feet feed and 5,400 r.p.m. The moisture content was 6 percent for this entire series of tests.

cting planing, probably cutting angle is the ost important. Most woods showed considerle variation in quality of work at different tting angles. The oaks, on the other hand, ve good results over a wide range of cutting gles.

The results of the tests with different speeds d feeds showed that the faster produced consistently better results with output one-third greater than the slower. The 5,400 r.p.m. speed is about as fast as cabinet planers often operate; planer matchers used in planing mills operate at much higher rates of feed made possible by larger cutter heads with a dozen or more knives. The high feed-speed combination in particular caused fewer chip marks than the

TABLE 10–3.—*Planing: Effect of feed and speed on quality of work* [1]

Kind of wood	Defect-free pieces at:	
	36-foot feed 3,600 r.p.m.	54-foot feed 5,400 r.p.m.
	Percent	*Percent*
Ash	52	64
Basswood	53	43
Chestnut	47	65
Cottonwood	17	23
Elm	17	26
Magnolia	50	72
Maple, hard	24	43
Maple, soft	19	37
Oak, red	72	74
Oak, white	60	60
Sweetgum	41	49
Sycamore	16	22
Tupelo, black	37	45
Willow	28	38
Yellow-poplar	50	54
Average	39	48

[1] Based on 4 cutting angles (15°, 20°, 25°, and 30°) and 6 percent moisture content for each feed-speed combination.

slower combination; chipped and raised grain were not greatly different under the two conditions, while the slower caused less fuzzy grain.

Among other planer adjustments experimented with was that of depth of cut. Four depths were tested: 1/32, 2/32, 3/32, and 4/32 inch. The shallowest cut gave much the best results, with progressively poorer work resulting as deeper cuts were made and some woods more markedly affected than others. Table 10–4 shows the percentage of pieces tested that were well-planed at each of the four depths of cut. While the operator at times has little choice as to depth of cut, where a preliminary roughing cut is practical he can often substantially improve the quality of the work.

Tests of the planing characteristics of lumber at different moisture content values showed that most hardwoods plane better when the moisture content is low. Lumber at 6 percent gave best results, that at 12 percent intermediate results, and that at 20 percent the poorest. Chipped, raised, and fuzzy grain were much more prevalent at 6 than at 20 percent, although the reverse was true of chip marks.

10.11. Shaping.—The shaper is intended primarily for cutting patterns on curved edges. It is of much less importance in the average prefabrication plant than the molder, which is used extensively for cutting a scarf or other pattern on straight strips.

Tests of hardwood samples at the Forest Products Laboratory showed wide variation in the shaping characteristics of the various species (table 10–1). Samples were graded on the basis of such shaping defects as raised, fuzzy, chipped, and torn grain, which, depending upon the amount, require more or less sanding.

Cuts made in a direction parallel to the grain or in a diagonal direction were consistently smoother than those at right angles to the grain. While moisture content had relatively little effect upon the quality of shaping, specific gravity, a measure of the hardness of wood, noticeably affected it. In general, the heavy woods shaped better than the light ones.

TABLE 10–4.—*Planing: Effect of depth of cut on quality of work* [1]

Kind of wood	Defect-free pieces at depth of cut of:			
	1/32 inch	2/32 inch	3/32 inch	4/32 inch
	Percent	*Percent*	*Percent*	*Percent*
Ash	58	38	32	26
Beech	76	40	34	24
Cottonwood	38	12	20	6
Elm	6	4	0	0
Magnolia	78	50	52	48
Maple, soft	40	28	30	14
Oak, red	74	56	36	28
Oak, white	58	34	22	24
Sweetgum	36	22	14	16
Sycamore	22	8	2	4
Tupelo, black	62	38	40	34
Willow	30	16	20	20
Yellow-poplar	64	36	44	34
Average	49	29	27	21

[1] Based on 30° knife angle only, 36-foot feed per minute at 3,600 r.p.m. and 6 percent moisture content.

10.12. Turning.—Although, as in the case of shaping, turning is of relatively small importance in the prefabrication of house parts, it likewise is a good index of the relative machinability of different woods. Turning tests on hardwoods at the Forest Products Laboratory disclosed that, while the spread in quality from best to poorest was not so wide as in most machining operations, the poorest woods yielded several times as many inferior turnings as the best (table 10–1).

Moisture content of the wood had little pronounced effect upon turning quality in the range of 6 to 12 percent, but at 20 percent there was a decided drop in quality. Most affected by this factor were the light woods, basswood, cottonwood, yellow-poplar, and willow. These woods

moreover, yielded the poorest results at all ranges of moisture content tested. Among the heavier woods, however, there was little pronounced difference in turning quality. No relationship was found between the number of annual growth rings per inch and turning quality. Lathe speed tests showed that, with a given diameter of turning, the higher speeds produced the better results.

10.13. Boring.—The importance of good boring in the prefabricating plant varies with the purpose of the boring. Where holes are desired through studding, joists, and other members merely for electrical conduits, pipes, or similar equipment, boring technique is not critical. Where, however, holes are drilled for load-bearing bolts or other fastenings, good technique that produces smoothly bored holes is important for its effect upon the strength of the joint. Because the area of wood in actual contact with the bolt is reduced in a roughly drilled hole, the bolt hole will be deformed at comparatively low loads, permitting loosening of the joint, and the load-bearing capacity of the joint will be lowered (sec. 13.13).

The bolt-bearing properties of holes bored in Douglas-fir plywood and Sitka spruce have been shown to be markedly affected by such factors as the rate of feed and the speed of the drill. Excessively high rates of feed tear out material beyond the true cutting line of the bit and damage other fibers in the wall of the hole. The rate of feed should be low enough to cut rather than tear through the piece, producing shavings, not chips. On the other hand, the highest speed compatible with production of a smooth hole and reasonable drill life should be used. Excessive speed should not, however, be used because the heat generated by friction may overheat a carbon steel drill, especially when deep holes are bored. Manufacturers usually recommend peripheral speeds of 300 to 400 feet a minute for high-speed drills.

Boring tests with hardwoods showed that, as a general rule, the heavier woods yield more smoothly cut and more accurate holes than do the light woods, with occasional exceptions (table 10–1). Hole size measurements disclosed differences from the actual size of the bit up to 0.005 inch on the average, with holes in a few pieces as much as 0.006 inch off size. The heavier woods required more power than did the lighter, softer woods.

It is advisable, when drilling holes in wood or plywood, to provide a wood base into which the drill can penetrate lightly on the under side of the piece being bored. In this way, tearing of the fibers on the under, or exit, side of the bored piece is avoided.

Punch presses are sometimes used to stamp holes in plywood. In punching, as with drilling, the harder, heavier woods punch more smoothly than the lighter, softer species. Birch plywood, for example, punches better than Douglas-fir.

10.14. Mortising.—The mortise and tenon joint is standard in many types of structures, and is suitable for use in joining framing members of panels as well as in other prefabrication operations. A smoothly cut and accurately sized mortise is essential to a strong joint. Mortises may be made with several types of machine cutters, such as the oscillating bit, the chain, and the hollow chisel.

Smoothness of cut varied widely among different hardwoods in machining tests with a hollow-chisel type of mortiser, depending to a great extent upon the direction of the grain with respect to that of the cut. Cuts parallel to the grain were passably smooth in all hardwoods tested. Chief variation in smoothness occurred in cuts across the grain. Hardwoods relatively high in mortising quality are the oaks, black walnut, birch, sycamore, hard maple, and beech (table 10–1). In general, the heavier, harder woods mortised more smoothly than did the lighter, softer species.

10.15. Sanding.—The chief purpose of sanding is to remove small defects in a planed surface in preparation for paint, varnish, or other finish. Such defects include fuzz, raised grain, knife marks, and small scratches. Unless removed by sanding, these defects often show even more plainly after certain finishes are applied than before. Sanding is therefore essential to the production of such surfaces as interior plywood panels and millwork that are to be carefully finished.

Sanding tests of hardwoods were conducted with two types of sanding machines, a belt sander and a drum sander. In only a few instances was the difference in scratching with the two types of sander substantial. Table 10–1

shows the average results obtained with the two types of machines

From the standpoint of freeness from fuzz, sanding with a belt and a drum sander produced comparable results except with those hardwoods that caused the most serious trouble with fuzzing, including the tupelos, sweetgum, birch, cottonwood, and yellow-poplar. For these, belt sanding was appreciably better than drum sanding.

Other factors that affected sanding results included moisture content, angle of grain, the type and size of abrasive used, and such operating conditions as the speed of the machine and the pressure on the abrasive.

In sanding plywood, particularly for use in stressed-skin panels, care should be taken to avoid excessive sanding. Too heavy sanding may reduce the thickness of the face ply sufficiently to cause a significant decrease in the strength of the skin sanded. Light sanding of plywood is sometimes helpful in preparing plywood surfaces for gluing (sec. 11.31).

10.2. MACHINING PROPERTIES OF MODIFIED WOODS.—Such densified woods as compreg, staypak, and compressed acetylated wood, together with similar commercial products marketed under various trade names and resin-treated compressed paper laminates such as papreg, are more difficult to machine than normal wood because of their increased specific gravity. In most cases, machining is necessary with cutting tools made of high-speed steel or tipped with such alloys as tungsten carbide, such as are furnished by manufacturers for the machining of plastics of various types. It is not generally necessary, however, to use metal-working equipment. The machining properties of densified woods can broadly be classified as midway between those of normal wood and metal.

Wood treated with synthetic resins to increase its resistance to swelling and shrinking, as for example, impreg, can be cut, bored, and otherwise machined with standard woodworking equipment, although the resin in the wood tends to dull cutting edges more rapidly than occurs with untreated wood. The tendency of tools to dull more rapidly is also noticeable over a period of time in the cutting of plywood and laminated wood bonded with resin glues.

Most resin-treated woods and some compressed woods can be sanded and buffed to a high polish. Marred surfaces of these materials can be restored by such treatment.

10.3. MACHINING PROPERTIES OF FIBERBOARDS.—The ease with which fiberboards can be sawed and otherwise shaped generally depends, as with wood, upon their density. Most of these products are easy to cut without serious dulling of tools. A few highly compressed board materials may require the use of high-speed steel cutting tools.

10.4. MACHINING PROPERTIES OF SANDWICH MATERIALS.—The type of equipment needed to cut and shape sandwich materials depends upon the basic materials of which such constructions are made. With the exception of the metal-faced constructions, woodworking equipment is usually suitable. Little machining other than sawing and boring is as a rule necessary, as these products are made up in panel form ready for use.

10.5. WOODWORKING MACHINERY.—The variety and adaptability of woodworking machinery is such that virtually any operation conceivable can be performed with power equipment requiring a minimum of manual skill on the part of the operator. Standard machines are available for most sawing, shaping, boring, and other operations. Where a special task is necessary, a little ingenuity can produce surprising results in adapting standard cutter heads to the requirements of the job. Most manufacturers of woodworking machinery are staffed with designers and engineers whose services are available when special machines are required.

The woodworking machines briefly described here are those used for the basic operations ordinarily met with in the manufacture of prefabricated houses. They represent, however, all the basic types of cutting equipment necessary to machine wood to any desired shape or size.

10.50. Saws.—The three basic types of woodworking saws are the band, circular, and jig saw. While their uses are to some extent interchangeable, each has its special tasks and advantages in volume production work.

10.500. Band Saws.—Band saws are made for a wide variety of uses. For ripping and resawing, large machines with blades 3 to 5 inches wide are generally used. The type most adaptable to the general wood shop is the band scroll saw,

which has blades from $\frac{1}{4}$ to 1 inch wide and is used particularly for cutting curved outlines and lines not parallel to an edge of the piece being cut. Essentially, a band saw consists of a table, wheels, guides, saw blade, and suitable guards. On most of the larger machines, the table can be tilted, usually 45° one way and 10° the other. Some, however, are built to permit bevel cutting by varying the blade angle. The band saw is generally used for resawing because of its thinner kerf.

10.501. Circular Saws.—The circular saw is one of the most-used machines in the prefabrication plant. Plants of any size usually have one or more power feed saws used exclusively for ripping and one or more for cross cutting. Beveling and mitering can be done with circular saws of the tilting-arbor type, while grooving and dadoing can also be done by means of special cutters. Circular saws are made in a variety of types and sizes, among which are the universal and variety saw. The universal type is equipped with two arbors to permit mounting of both rip and cross-cut blades, either of which is brought into use by simply turning a hand wheel controlling the positions of the arbors. The variety saw employs a single arbor and is generally fitted with mortising and boring attachments. The main structural features of either machine are similar, however, and include the arbor, saw blades, table, ripping fence, crosscutting and mitering fence or gage, and a substantial base.

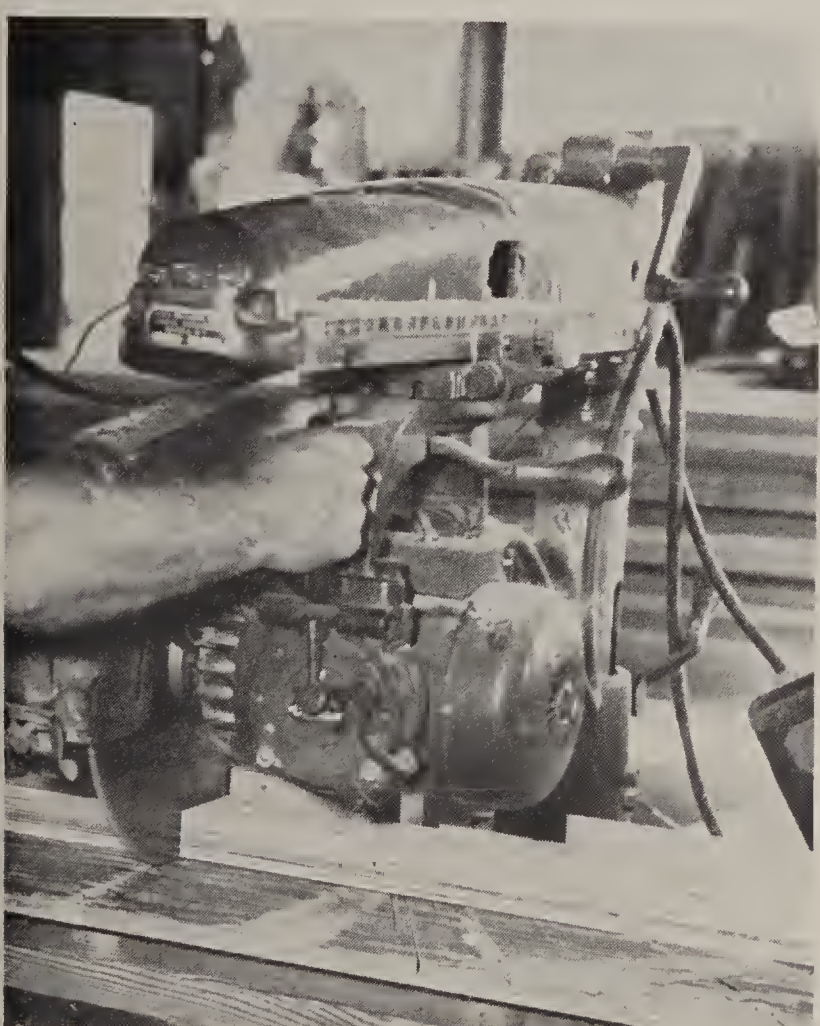

FIGURE 10–1.—Electric cutoff saw.

In recent years circular saws mounted on a radial arm above the work have come into wide use. These are usually equipped for variable angle cutting (fig. 10–1). Such saws can also be used for dadoing (fig. 10–2) or other cutting operations with special attachments.

10.502. Jig Saws.—The jig saw differs radically in construction from the band scroll saw (sec. 10.500) although the type of work for which it is intended is very similar. The jig saw is more adaptable than the band scroll saw for cutting small, sharp curves because much smaller and finer blades may be used. Inside cutting also is better accomplished on the jig saw, since the blade is easily removed and inserted through an entrance hole bored in the stock. The jig saw consists mainly of a base or frame, driving mechanism, table, tension mechanism, guides, and saw blade. There are comparatively few cutting operations in house prefabrication, however, where it is especially well adapted to use in preference to other saws.

10.51. Planers (Surfacers).—The planer, or surfacer, is used mainly for finishing surfaces of flat stock and reducing stock to uniform thickness, although it is adaptable to such work as scarfing solid wood stock. These machines are available with either one cutting head or two, so that one or both sides of a piece may be planed at one operation. The 24- and 30-inch surfacers, suitable for fairly wide panels, are most commonly used in the wood shop, although faster machines for narrower material are typical of the planing mill. The essential parts include the frame, table or bed, feed rolls, cutter head, chip breaker, and pressure bar. The table can be raised or lowered according to the thickness of the stock to be planed.

Warped or twisted stock should always be straightened on one surface with a jointer (sec. 10.52) before being put through the planer.

The planer is a complex machine requiring many different adjustments (sec. 10.10). Among these, perhaps the most important is that of the cutting angle of the knives. Figure

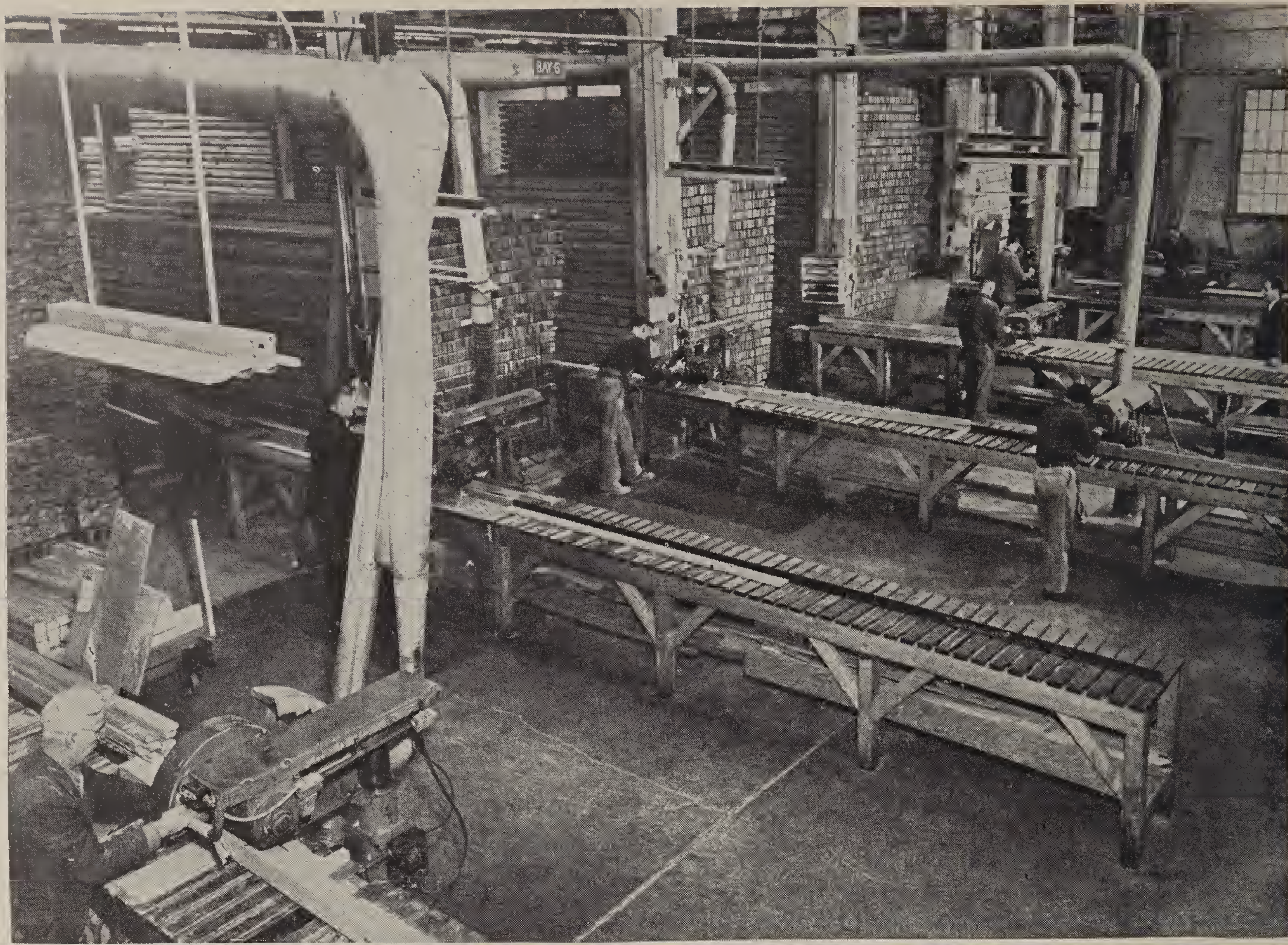

FIGURE 10–2.—Cutting gains in framing members of prefabricated panels with a dado-head attachment on a cutoff saw.

10–3 illustrates the terms used in connection with planer knives. Cutting angle may be altered by changing cutter heads or by grinding a "back bevel" on the knife edge.

The molder is a related machine that is designed primarily for cutting patterns on relatively narrow lumber. To do this, it uses knives ground or milled to a pattern on their cutting edges instead of in a line like planer knives. It usually carries four cutterheads and is able to machine all four sides of a piece at once. It is extensively used in prefabricating plants for rapid production of framing or other stock cut to specified pattern (fig. 10–4). Figure 10–5 illustrates an adaptation used for cutting a shallow depression in the face of a plywood sheet along its edge. The knives of this cutter were ground to the desired curvature to produce a concave cut.

10.52. Jointers.—The jointer is similar to the planer, except that it has only one cutter head

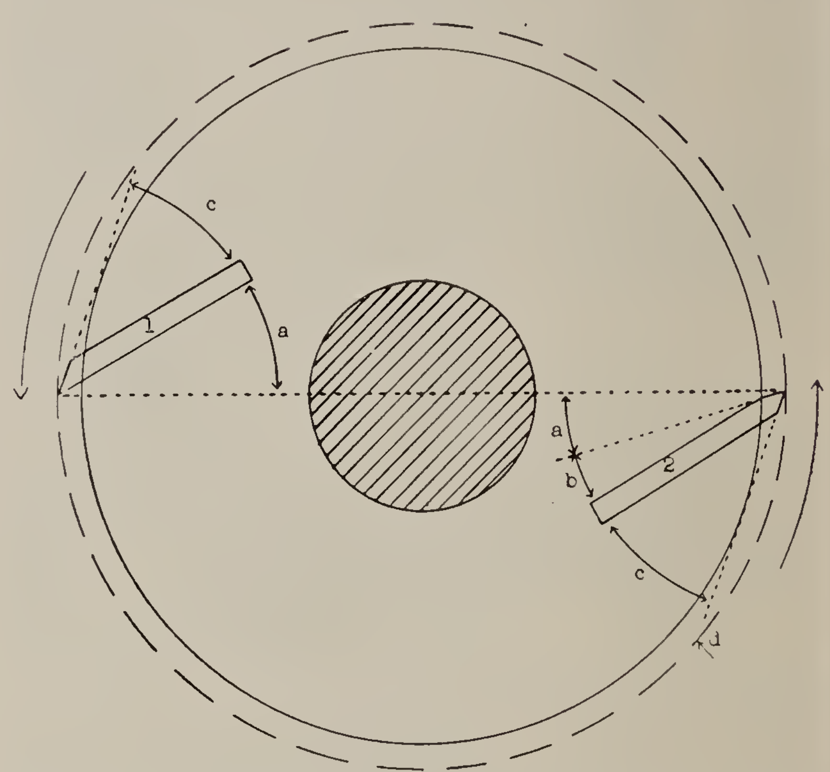

FIGURE 10–3.—Terms used in connection with planer knives: a, cutting angle; b, cutting bevel; c, clearance bevel; d, cutting circle; 1 and 2, planer knives.

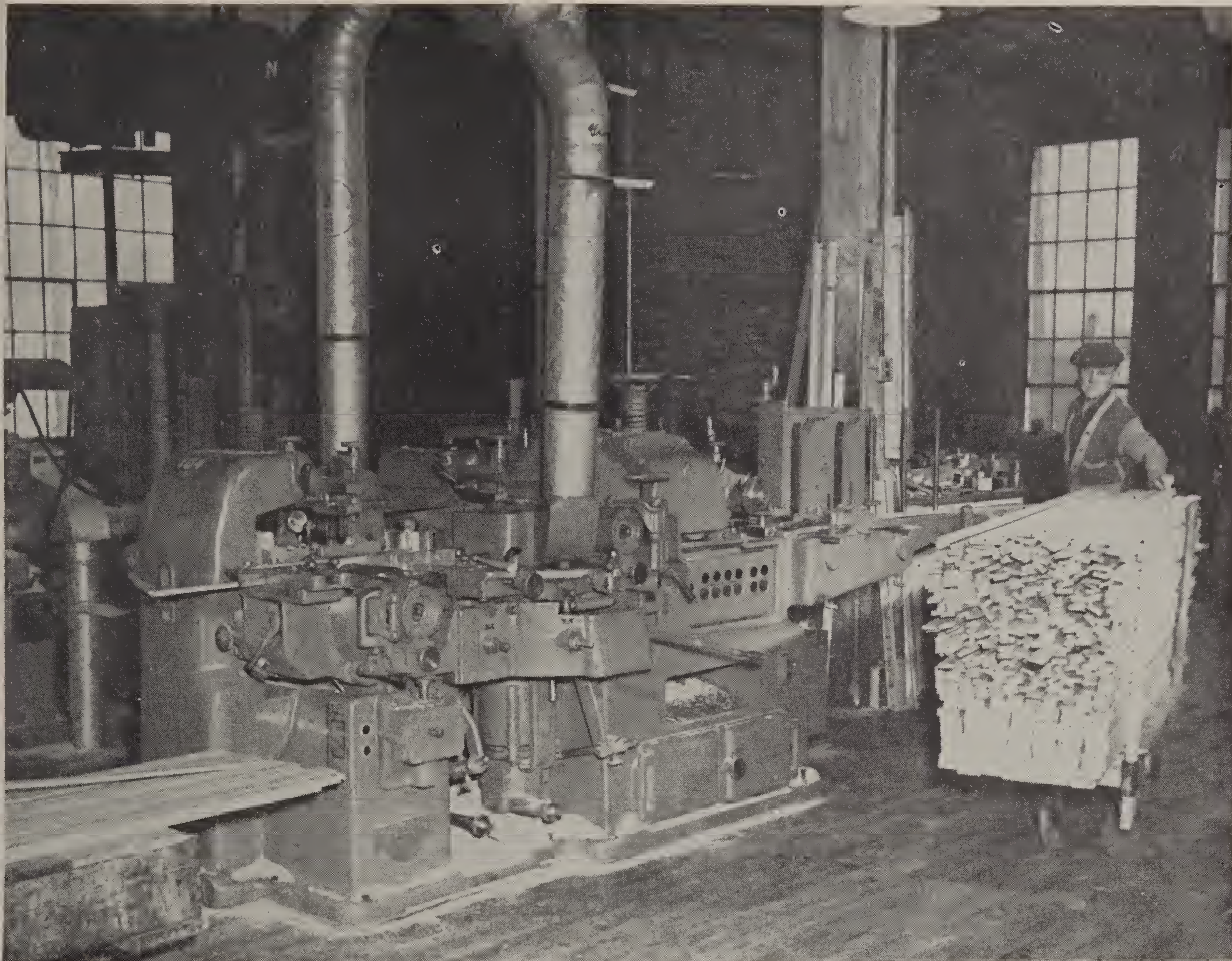

FIGURE 10–4.—Molder being used to shape panel frame members.

located below the table and that the feed is usually by hand. Its primary use is to cut a true face and edge on stock that has been warped, twisted, or has other irregularities. The table is in two sections, the infeed section being raised or lowered to control the thickness of the cut, whereas the planer table is generally in one section that is raised or lowered as a unit to control the thickness of the finished piece. By tilting the fence, bevel edges can be cut. This machine can also be used for tapering, end planing, and rabbeting.

10.53. Shapers.—The shaper is used mainly for stock irregular in outline and for cutting scarfs in narrow solid stock or wide plywood. The shaper consists essentially of a vertical spindle, with cutter head, table, and base. Generally the knife with cutting edge ground to the desired shape of cut is used, but solid cutters milled to the desired shape are also available. Stock may be cut roughly to shape with a band or jig saw before being finished on the shaper. When a number of pieces of the same pattern are to be shaped, templates are often used to regulate the depth of cut by bearing against the shaper collar.

The principle of the spindle shaper is employed for various specialty operations in prefabricating plants. Figure 10–6 shows a type of cutter head used to cut a spline groove in a panel. A somewhat similar cutter head with the motor and spindle set at an angle and the cutting edge ground to the desired shape is shown in figure 10–7 as used to cut a grooved joint of V shape in a panel edge.

10.54. Boring Machines.—Boring machines are made in various types and, as required, in combination with other specialty woodworking de-

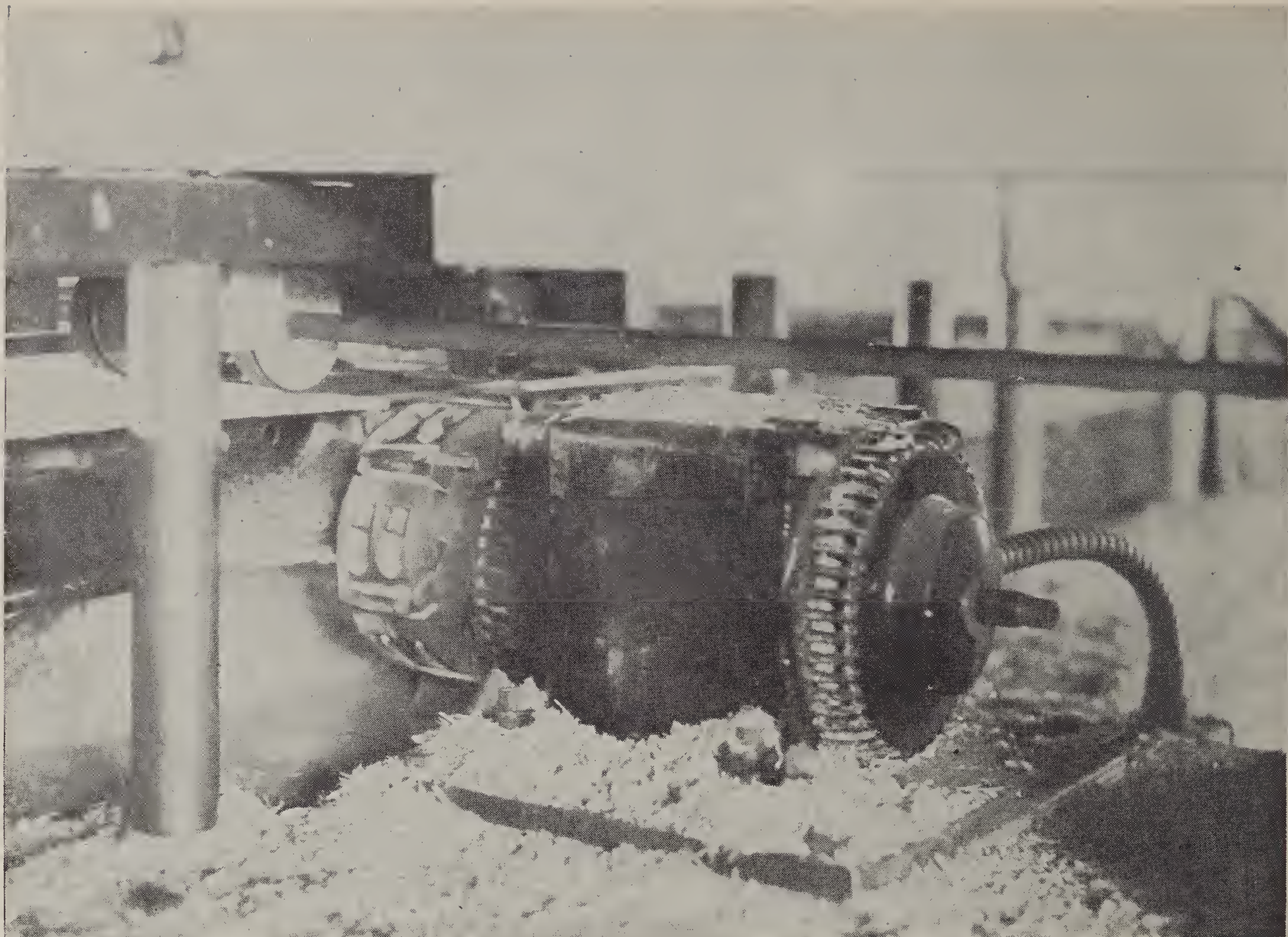

FIGURE 10–5.—Adaptation of molder-type cutter head with shaped knives to make wide concave cut in the face of a plywood sheet along the edges.

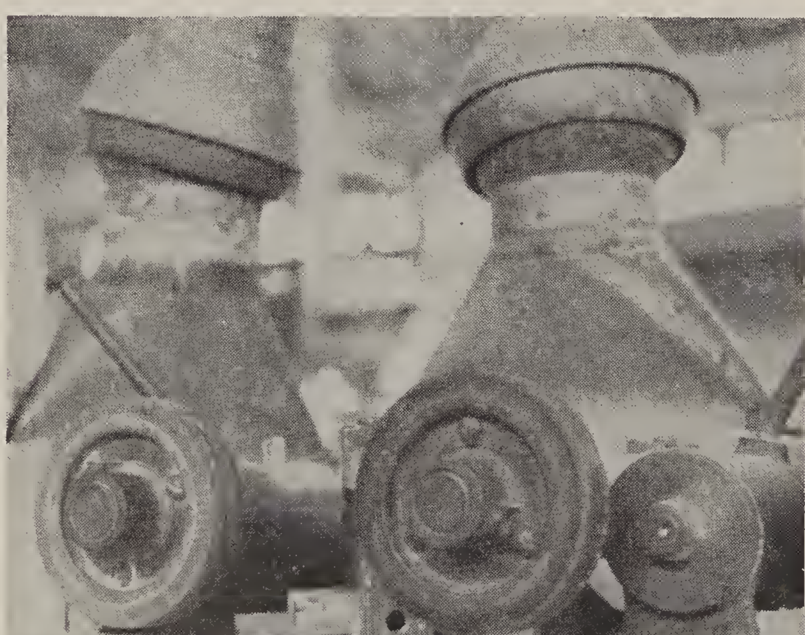

FIGURE 10–6.—Vertical cutter head used to cut a spline groove in a panel edge member.

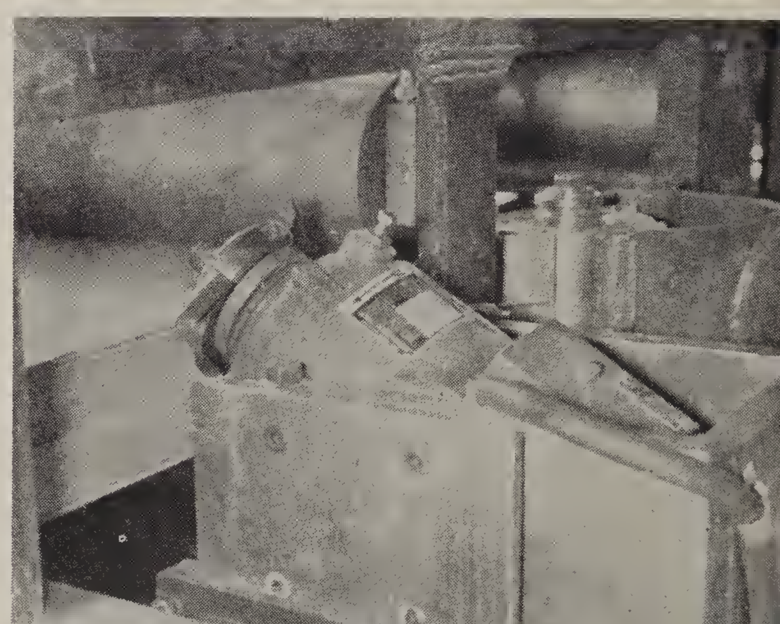

FIGURE 10–7.—Shaper-type cutter head set at an angle to groove a panel edge for a special joint.

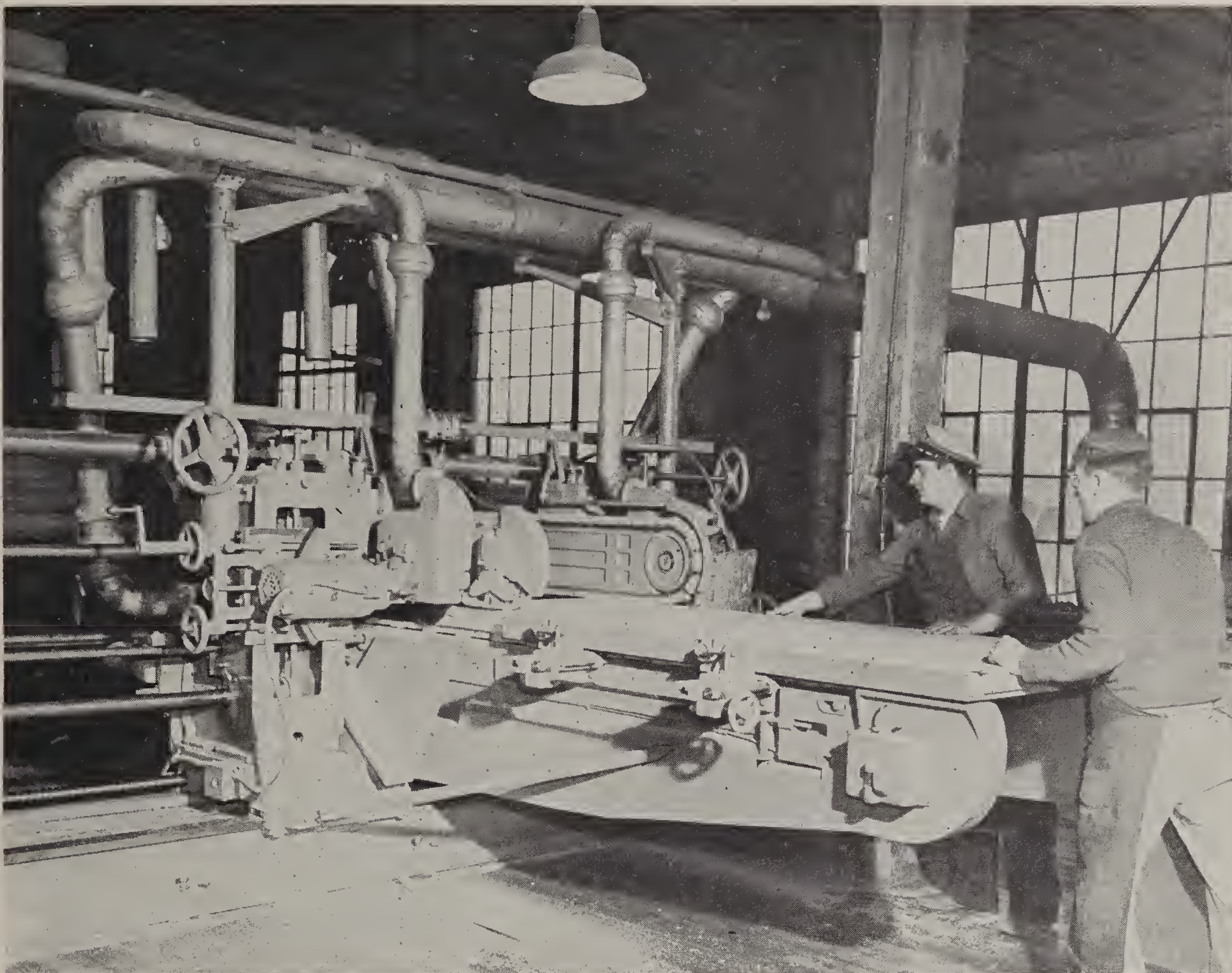

FIGURE 10–8.—Sizing a stressed-cover wall panel in a double-end tenoner.

vices. The most common is the single vertical spindle type fed either by a hand lever or foot pedal. Some prefabricating plants are equipped with multispindle power-feed machines capable of cutting a series of holes of the desired spacing, angle, depth, and size along the length of the stock at one operation. Their most common uses in the plant are for cutting bolt holes and passages for electrical conduits, plumbing pipe, and similar equipment. The single-spindle type generally has a tilting table for boring holes at any angle.

Mortisers of the hollow-chisel type are adaptable for use in standard boring machines.

10.55. Tenoners.—Tenoning machines are available in either single- or double-end types. It is equipped with cutoff saws, tenoning heads, and vertical spindles for use of other cutting heads. The double-end tenoner is a widely used machine in the prefabrication plant and has a large output. It is versatile and can be used for cutting framing members and other stock to accurate length, sizing finished panels to precise dimensions (fig. 10–8), grooving panel edges for splines, and similar operations.

The equalizer is an adaptation of the double-end principle used primarily to cut plywood sheets to exact width for prefabricated panels. The type shown in figure 10–9 is equipped with cutter knives. Other types are equipped with saws.

10.56. Dado Machines.—Several types of dadoing machines are in use in prefabricating plants to cut gains in framing members and for similar operations. The basic dado head consists of two circular saws mounted on a horizontal spindle and separated by sufficient cutters to cut gains of the desired width. It can be used on some

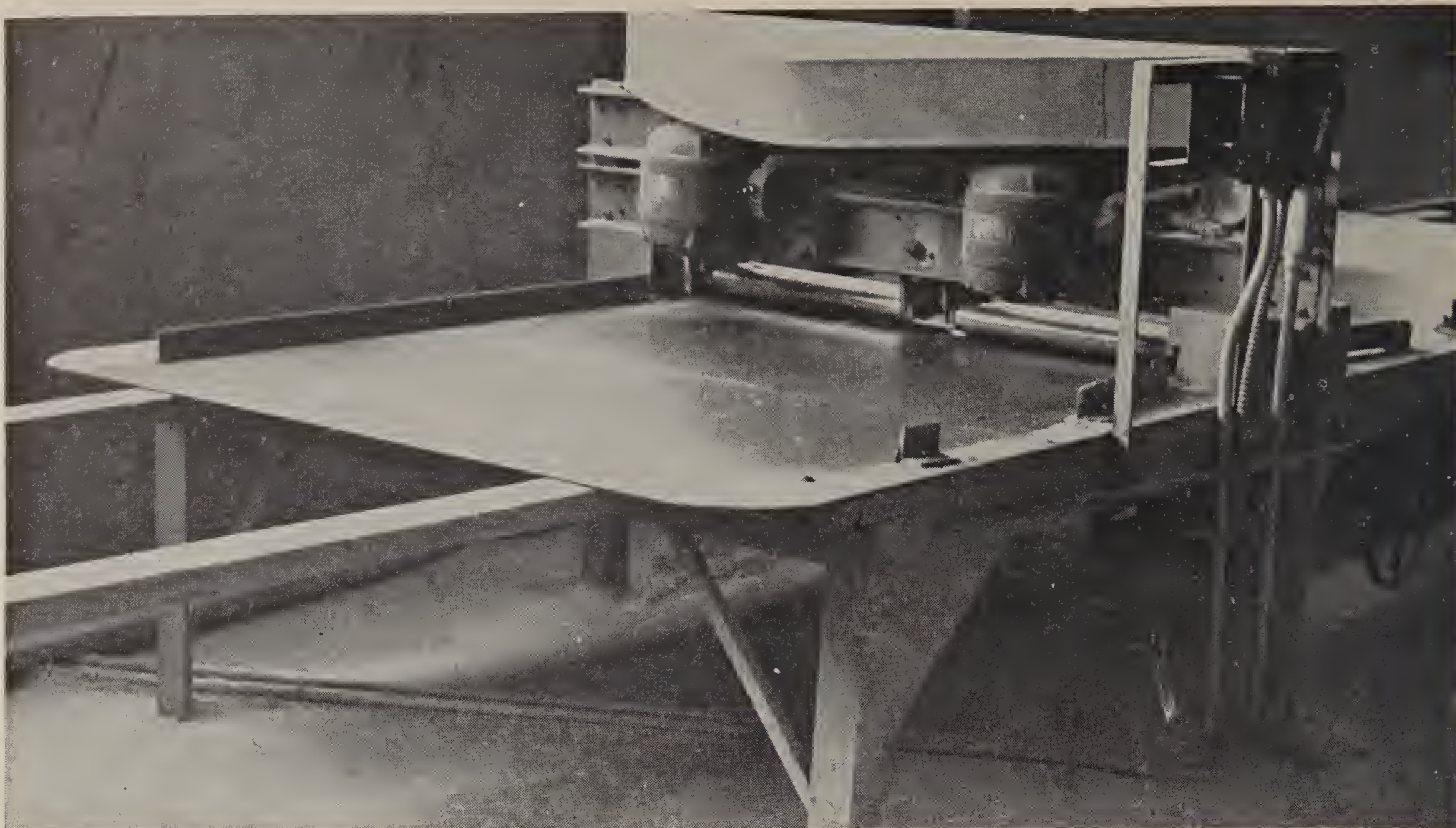

FIGURE 10–9.—Equalizer equipped with cutter knives on vertical spindles for trimming plywood to exact width.

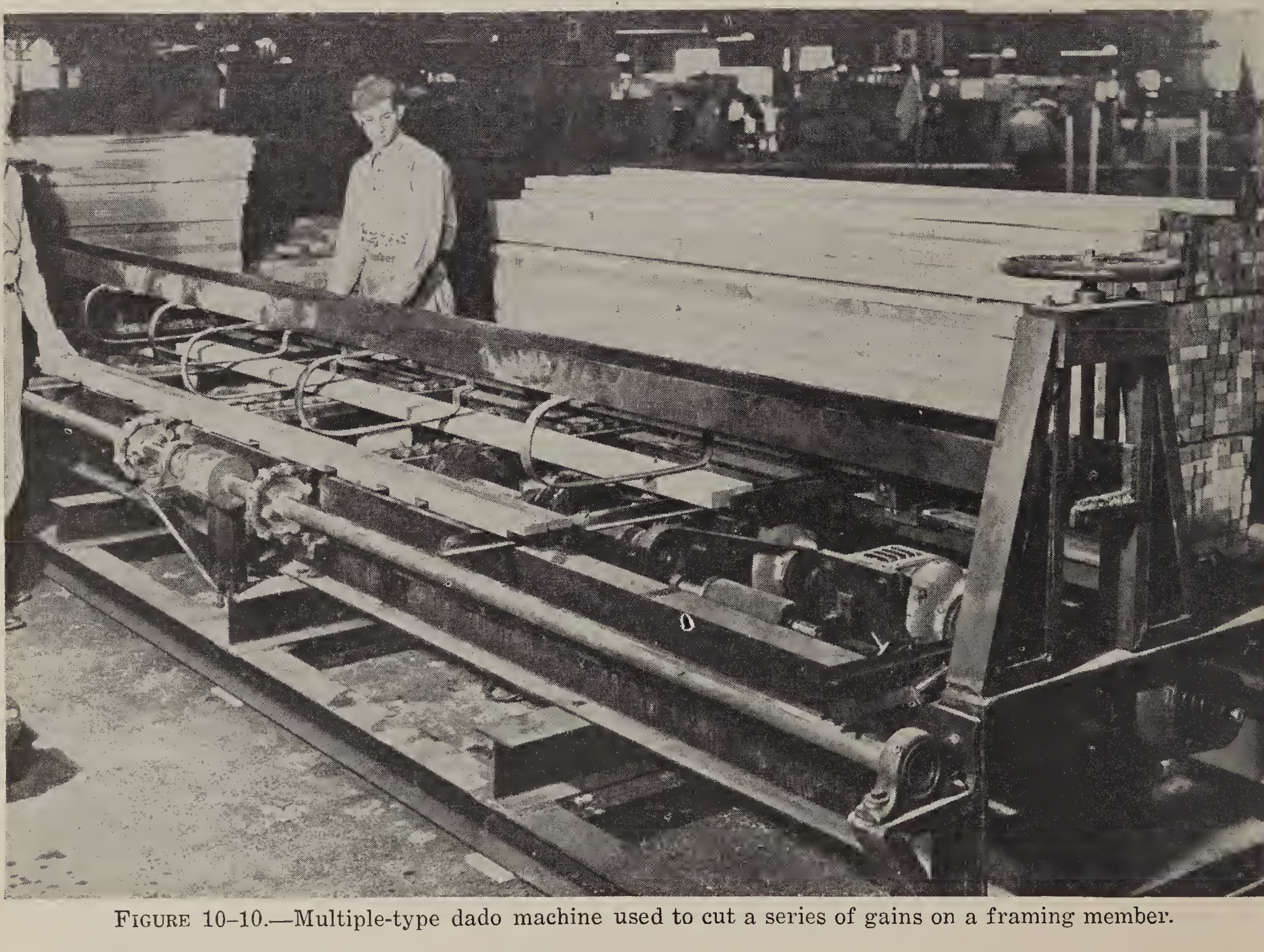

FIGURE 10–10.—Multiple-type dado machine used to cut a series of gains on a framing member.

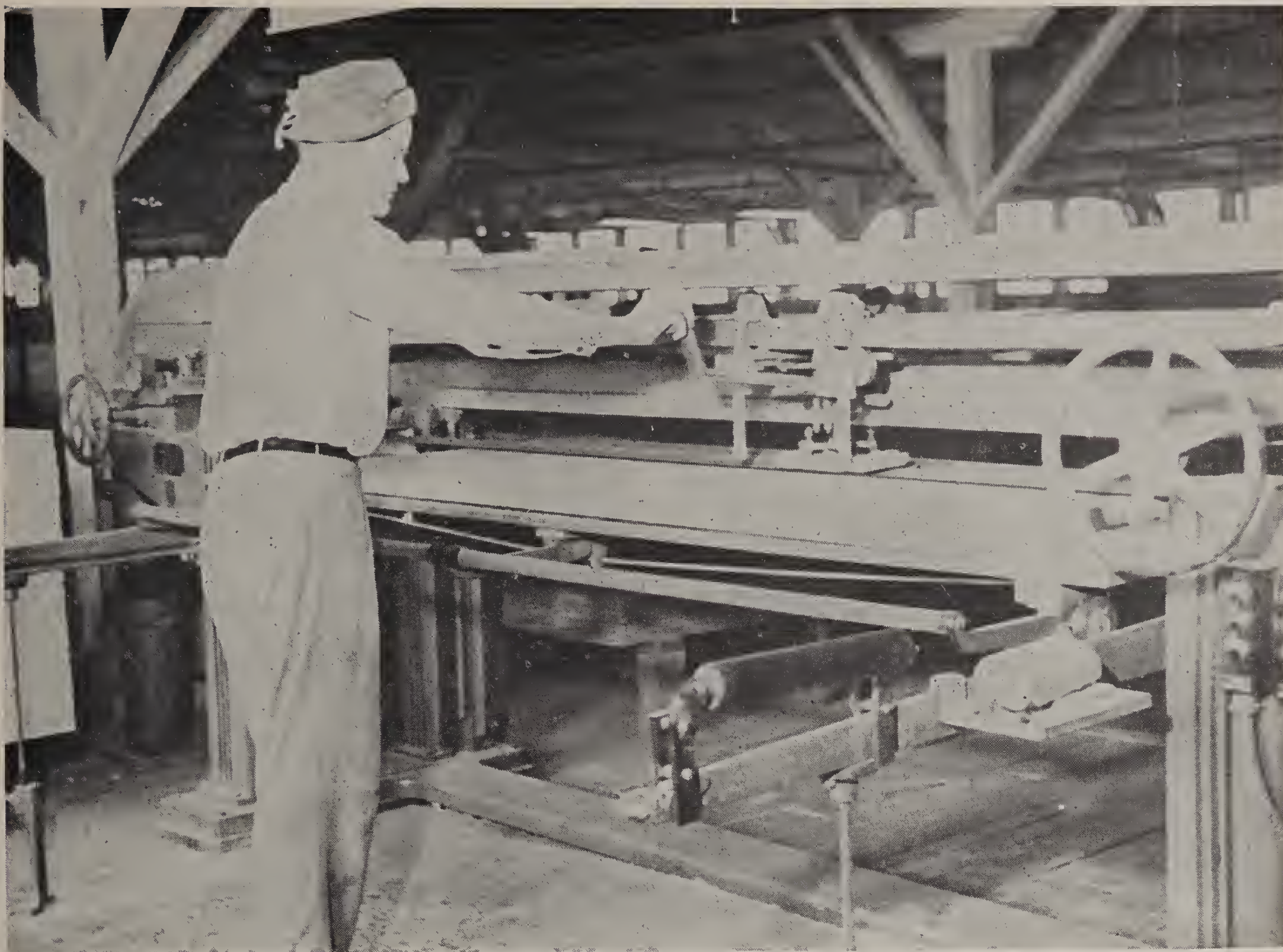

FIGURE 10-11.—Sanding plywood panel with a belt sander.

types of cutoff saws (fig. 10–2) or, for multiple cutting of gains, multiple-type dado machines are available (fig. 10–10).

10.57. Sanders.—The common types of sanding machines used in the prefabricating plant are the belt sander (fig. 10–11) and drum sander. Other types found in woodworking shops are the disk and spindle sanders used chiefly for cabinet work and other small stock. The belt and drum sanders are more adapted to smoothing planed surfaces of solid stock and plywood.

Sanders smooth wood surfaces by the scratching action of various types of abrasives. These abrasives, or grits, come in a wide variety of sizes, and it is general practice with any given wood to use the coarsest grit that will not make scratches visible to the eye. Figure 10–12, *A*, shows how sander dust appears under the microscope and 10–12, *B*, the scratching effect of different sizes of grit on hard maple. In addition to rotating, the drums of a drum sander oscillate slightly, so that any scratches that result are wavy, making "snake tracks." With a belt sander the scratches are straight lines. In section 10.15 are given some comparative results of sanding done with belt and drum sanders. The drum sander may be used to surface the gluing faces of panel frames after assembly of the frames on jigs in order to smooth out any slight differences in plane of adjoining frame members which might cause gaps in the glue bond. Pronounced differences in plane, however, will require the use of a cutting tool and should be avoided on the jig, as they are indicative either of faulty jointing of the members or careless assembly.

10.58. Portable Machines. — Many types of woodworking machines today have their counterparts in portable equipment, and such equipment finds extensive use in the prefabricating plant. Among these are planers, circular saws, disc-type sanders, routers, and borers (figs. 10–

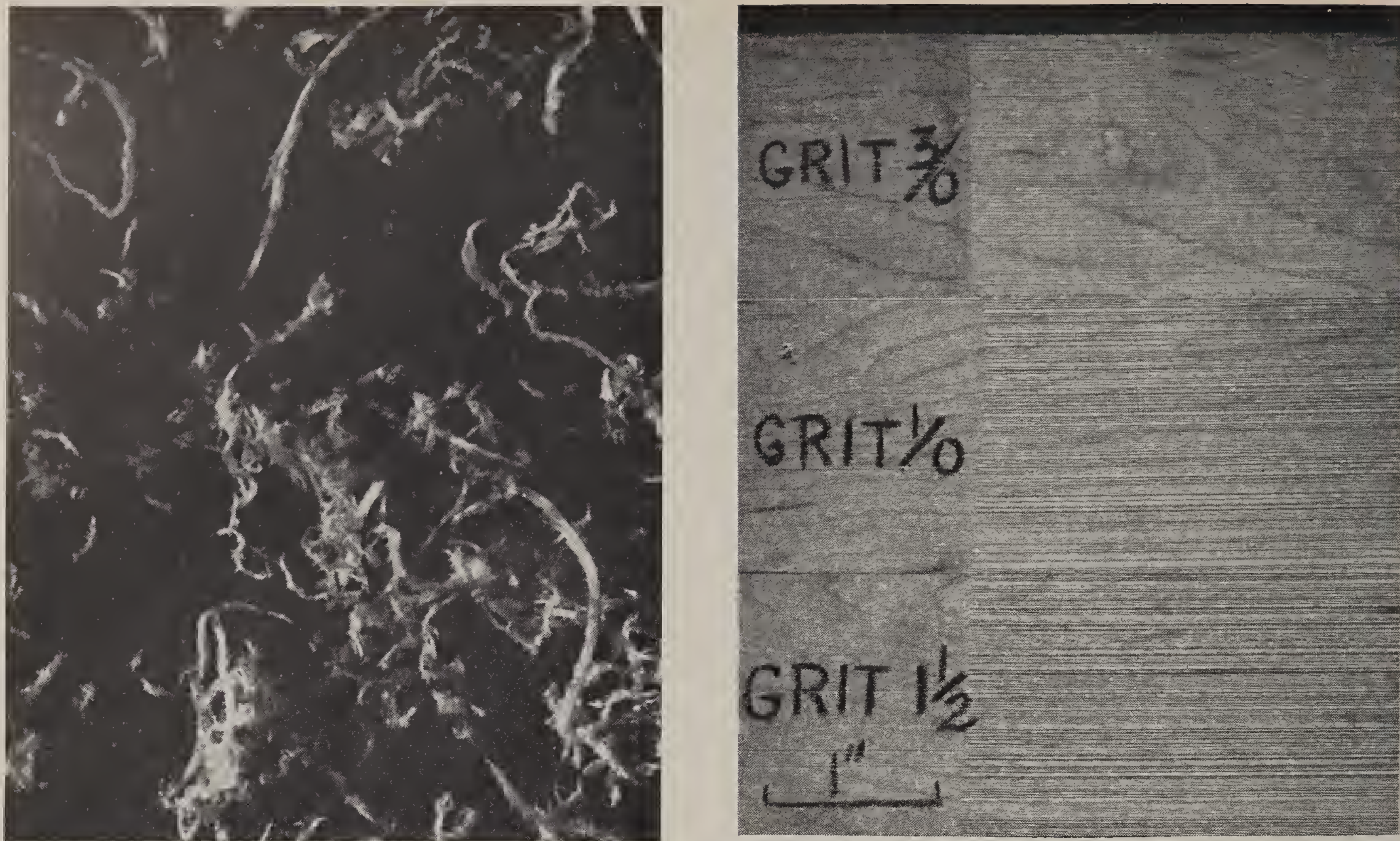

FIGURE 10–12—Sander dust (left) made by No. 1½ grit (greatly enlarged); scratching tendencies (right) of three different sizes of grit in hard maple.

FIGURE 10–13.—Power hand planer.

13, 10–14, and 10–15). The router is a particularly useful machine for cutting out openings in plywood sheets for windows, doors, and other fixtures, since its bit is machined both to drill the entry hole and cut out the piece. For cuttings of large size, templates are usually used to guide the cut.

FIGURE 10–14.—Portable circular saw being used to cut several sheets of fiberboard along a template for a door opening.

FIGURE 10–15.—Portable router being used to cut a window opening in a plywood panel along a template.

10.59. Hand Tools.—Despite the wide range of power-driven woodworking equipment available for cutting and shaping operations, such common hand tools as screw-drivers, hammers, saws, planes, glue guns, caulking guns, and wrenches of various shapes and sizes are still essential in the prefabricating plant. Most of these tools are used in assembly work, from nailing or otherwise fastening framing members together on the jig to applying window, door, and other trim.

Definite progress has been made in speeding such operations as nailing, screw driving, glue spreading, and caulking. Figure 10–16 shows a stapler-type nailer used to nail glue plywood to the frame of a house section.

10.6. REFERENCES.

(10–1) DAVIS, E. M.
1942. MACHINING AND RELATED CHARACTERISTICS OF SOUTHERN HARDWOODS. U. S. Dept. Agr. Tech. Bull. No. 824, 42 pp. Illus.

FIGURE 10–16.—Stapler-type nailer used for rapid nail gluing of cover materials to frames.

GLUES AND GLUING

11.0. GENERAL.—Several types of glues are in current use in the manufacture of prefabricated houses. Of these, soybean glue and hot-press phenol glues are used almost exclusively for the bonding of veneers in the manufacture of flat plywood. Urea-resin glue is also extensively used for flat plywood production. Casein glue and several types of synthetic-resin glues are used in the various secondary gluing operations. Animal and vegetable glues have been used widely for bonding wood but are not considered suitable for housing applications because of their limited durability under occasional severe service conditions. Blood albumin glues have largely been superseded in the manufacture of plywood by some of the synthetic-resin glues.

11.1. TYPES OF GLUE FOR WOOD.

11.10. Casein Glues.—The forms, characteristics, and properties of water-resistant casein glues have remained substantially the same for many years except for the addition of preservatives. The dried casein of milk is the basic constituent of this class of glues. It is combined with alkalies or alkali-producing chemicals which, when mixed with water, render the casein soluble. The addition of lime or other chemical causes the glue to set by becoming insoluble and so to retain a part of its strength even when saturated with water. Casein glues for housing should preferably contain preservatives to make the set glue resistant to molds and other deteriorating organisms.

Prepared casein glues are sold in powder form to be mixed with water to the consistency of a thin paste. The paste is ordinarily applied at room temperature, but there is some evidence to indicate that these glues may be satisfactorily used at lower temperatures if the pressure can be maintained for longer periods. Casein glues have been used for many years and the details of their preparation and application are generally well known (*11–3*).

11.11. Soybean Glues.—This type of glue, used mainly for bonding plywood, is similar to the casein glues in that it is made of a protein-base, soybean meal, to which are added alkalies and lime together with certain other ingredients to produce a glue with a moderate amount of moisture resistance. The soybean meal is a residue of the extraction of oil from the soybean. The addition of preservatives to soybean glue is desirable, as in the case of casein glues. Soybean glues may be used either by hot pressing or pressing at room temperatures. Soybean glues are not commonly sold in completely prepared form like the casein glues but are usually partially compounded by the user.

11.12. Synthetic-resin Glues.—The term "synthetic resin" refers to a large class of materials produced by chemical reactions from relatively simple reagents. The first such materials resembled certain of the natural resins in their general appearance, but some of the more recent synthetic resins bear little, if any, resemblance to the natural resins.

The development of synthetic-resin glues for wood has provided bonding materials superior in a number of important properties to those formerly used. Most bonds in prefabricated housing require glues that retain their strength and durability under warm, moist conditions and even after exposure to water. In these properties the synthetic-resin glues are outstanding.

These glues may be classified either as thermosetting or thermoplastic. The phenol, resorcinol, melamine, and urea resins belong to the thermosetting class and once the condensation reaction, which is hastened by heating, is complete, little or no subsequent softening occurs even though the temperature is increased beyond the original setting temperature. Glues of this type have various temperature ranges from 75° to 320° F., depending on the type of glue, at which they cure at practical rates. In general, any thermosetting glue can be made to

harden or cure more rapidly by raising the curing temperature, thus decreasing the length of time required under pressure.

Thermosetting resin glues may be classified according to the temperature required to cure them in a reasonable length of time, as follows:

Glue classification	Minimum temperature for satisfactory curing within practical time limits [1]
Hot-setting	Hot-setting glues require higher temperatures than those commonly attained in heated chambers for which the maximum is about 210° F.
Intermediate-temperature setting	Intermediate-temperature-setting glues require heating in excess of normal room temperatures (about 65° to 80° F.) but do not necessarily require temperatures above about 210° F., the maximum that can ordinarily be attained in a heated chamber.
Room-temperature-setting	Room-temperature-setting glues require no heating above normal room temperatures, which commonly range from about 65° to 80° F., but do not cure satisfactorily at lower temperatures.
Cold-setting	Cold-setting glues set or cure below normal working room temperatures (about 65° to 80° F.) and some may set satisfactorily at temperatures as low as 32° F.

[1] Glues in each designated classification vary as to their minimum curing temperature and may not be assumed to cure at all temperatures within the given range.

This classification is made merely for the sake of convenience in discussing the glues and does not imply that every glue represented as belonging to a certain class necessarily cures within the temperature range given above under all conditions. Since it has been established that the same adhesive with a given construction may require different curing temperatures when used with different species, certain glues may fall under one class when used with some species and under another when used with other species. By allowing different times for curing, the temperature requirement may also vary from one classification range to another.

Synthetic resins of the thermoplastic class soften whenever the temperature reached is above a softening range that is characteristic of each particular type of resin. A thermoplastic resin must ordinarily be first heated and then cooled under pressure in using it as an adhesive. Glues of the strictly thermoplastic type are not recommended for the gluing of wood in prefabricated houses because of their tendency to flow at elevated temperatures and to creep under sustained load.

11.13. Hot-setting Phenol-resin Glues.—The hot-setting phenol resins are derived from the reaction of phenol and formaldehyde, and are also known as phenolformaldehyde resins. They are commonly supplied as a dry film, a powder to be dissolved in water or alcohol, or a liquid syrup. These glues may often be applied to the veneers several days or weeks prior to the pressing operation. They are then usually pressed at temperatures of 280° to 320° F. Phenol-resin glues are sometimes extended by the addition of blood albumin, and there is some interest among glue manufacturers in similar extensions with vegetable proteins and starches, in order to reduce the costs of the glue. In general, extension reduces the durability of the glue bond somewhat below that of the straight phenol resins.

11.14. Intermediate-temperature-setting Phenol-resin Glues.—These glues, also derived from phenol or phenolic-type compounds and formaldehyde, are of more recent origin and were developed to fill the needs for durable glues, particularly for laminating and assembly gluing constructions that can be cured at temperatures between those of a normal room and 210°F. As with all thermosetting resin glues, the rate of curing of the glue increases as the temperature increases. Curing can be accomplished by heating the assembled panels under pressure in a heated chamber by means of radio frequency, or in hot presses.

These glues are marketed either as powders or liquids, usually with separate hardener to be added at the time of mixing. Glues of this type may be acid or alkaline in nature but, at present, the nearly neutral or mildly alkaline glues are preferred because there is evidence that strongly acid glues have a weakening effect on wood (*11–4*).

11.15. Room-temperature-setting Urea-resin Glues.—These glues are made by reaction of urea and formaldehyde, and are also called urea-formaldehyde resin glues. They are marketed either as dry powders with separate or incorporated hardeners, or as liquid syrups with separate hardeners. The powders are mixed with water in specified proportion for use as glues.

Of two wood surfaces to be bonded, a special highly acid hardener is sometimes applied to one, while resin is applied to the other and the joint assembled with a very short assembly period. This so-called "separate application" technique is not recommended for gluing house panels because of the difficulty in maintaining adequate control over gluing conditions and because the presence of large amounts of acid is likely to have a harmful effect on the cured glue in the joint.

11.16. Special Urea-resin Glues.—Certain urea-resin glues are formulated for hot-press application only at curing temperatures of 240° to 260° F. and they are used for manufacture of plywood, particularly hardwood plywood.

Some urea glues are specially formulated for extension with wheat or rye flour in order to reduce costs. They are used mainly for the manufacture of intermediate grades of plywood. These grades vary considerably in quality, depending largely upon the amount of flour extension.

Urea-resin glues are not recommended for exterior use in housing and highly extended mixtures are not recommended for interior use.

Fortified urea-resin glues have been marketed for special purposes, as to improve the resistance to hot water. These glues are mixed, usually with resorcinol or melamine resins, to produce adhesives more resistant in certain respects than the unfortified urea resins. Some of the melamine-fortified urea resins contain as much as 50 percent of the fortifying agent and produce joints of high initial resistance to severe exposures. Fortified urea-resin glues available at present will not harden adequately at curing temperatures below 140° F.

11.17. Melamine-resin Glues.—The melamines are resins derived from the reaction of melamine and formaldehyde, and are also known as melamine-formaldehyde resins. At present these are available in two types, one for hot pressing at 240° to 300° F., and an intermediate-temperature-setting one for bonding at 120° to 200° F. These glues are used primarily for bonding plywood, although the intermediate-temperature-setting type can also be used for the assembly of house panels where heat may be applied to the joints.

11.18.—Resorcinol-resin Glues.—The resorcinol resins are derived by reaction of resorcinol and formaldehyde and are also known as resorcinol-formaldehyde resins. Resorcinol is a compound related chemically to phenol, and resorcinol resins are similar in many respects to the phenol resins, their chief differences being their greater reactivity and more rapid setting at lower temperatures. They are supplied as liquid syrups with separate hardeners. These glues cure adequately at 75° F. for most housing applications when pressure is maintained for several hours. They set slowly and develop water resistance slowly at temperatures below room temperature. For certain applications on low-density species where adequate pressure may be maintained for long periods, these glues may be used at temperatures as low as 40° or 50° F.

11.2. PROPERTIES OF GLUES FOR WOOD.

11.20. General.—The properties of the glues used in prefabricated house construction vary widely. Specific information on these properties has been obtained at the Forest Products Laboratory in large part from tests of joints and wood assemblies. The data here presented are based mainly on these joint and assembly tests.

11.21. Effect of Moisture on Glues.—The resistance of different types of synthetic-resin glues and of casein glue in plywood joints after exposure to severe moisture and temperature conditions is illustrated in figures 11–1, 11–2, and 11–3. Various casein glues were used, some with preservative (fig. 11–1) and some without (fig. 11–2). The data on casein in figure 11–3 are for glues both with and without preservative. No similar data are available on soybean glues.

11.22. Effect of Micro-organisms on Glues.—Bacteria and fungi present in casein may live and multiply in casein glue lines under proper conditions of temperature and moisture. Bacteria are most likely to multiply in protein glues

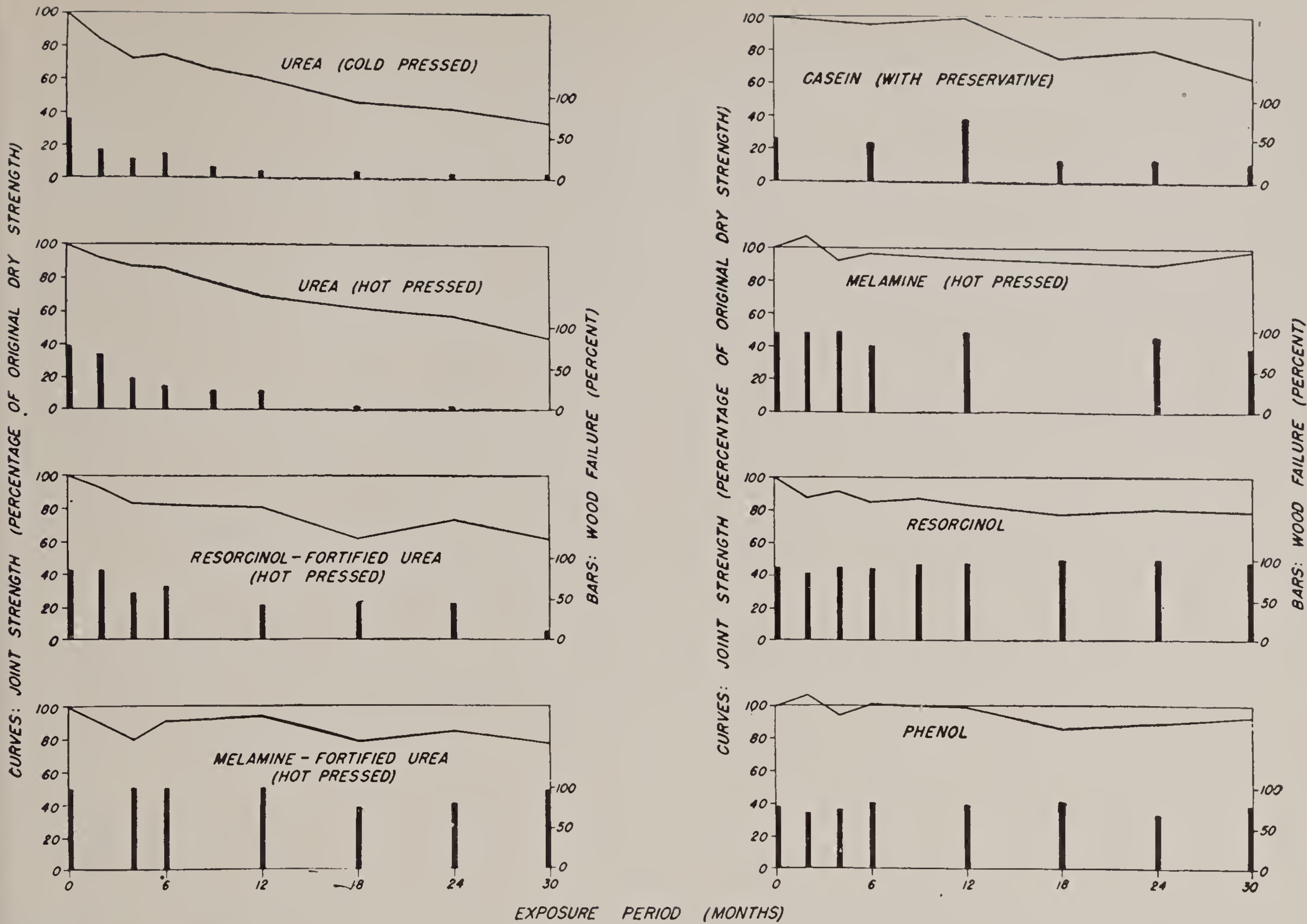

FIGURE 11–1.—Resistance of yellow birch plywood, glued with 8 types of glues, when exposed to a repeating cycle consisting of 2 weeks at 97 percent relative humidity and 80° F., followed by 2 weeks at 30 percent relative humidity and 80° F.

that are thoroughly saturated with water. Fungi are most likely to multiply in protein glues exposed to high atmospheric relative humidity. The effects of fungi on glues were studied at the Forest Products Laboratory by exposure of groups of birch plywood specimens to a temperature of 80° F. and 97 percent relative humidity.

Casein glue lost most of its strength within a short time. The addition of preservative to this glue improved its resistance to fungus attack noticeably. Although similar tests have not been made on soybean glues, it would be expected that, because of their similarity to casein glues in composition, they would show comparable effects due to attack by micro-organisms.

The cold-press and hot-press urea resins lost strength somewhat more slowly but very noticeably. The fortified urea, hot-press phenol, resorcinol, melamine, and intermediate-temperature phenol glues showed little or no effect of micro-organisms on the glue, although these organisms attacked the wood, lowering its strength and causing nearly complete wood failure.

11.23. Effect of Temperature on Glues.—Figure 11–3 shows the results obtained after exposure of birch plywood specimens to a repeating cycle consisting of 8 hours at 158° F. and 20 percent relative humidity followed by 16 hours at 80° F. and 65 percent relative humidity.

Cold-press urea resins showed the greatest decline in strength and wood failure under these conditions. Joints made with cold-setting urea resins lost nearly one-half their original dry strength during the first 9 months and then continued to lose strength slowly throughout the remainder of the $2\frac{1}{2}$-year exposure period. Wood-failure values were negligible after 6 months of exposure. Hot-press and resorcinol-fortified urea resins showed a more

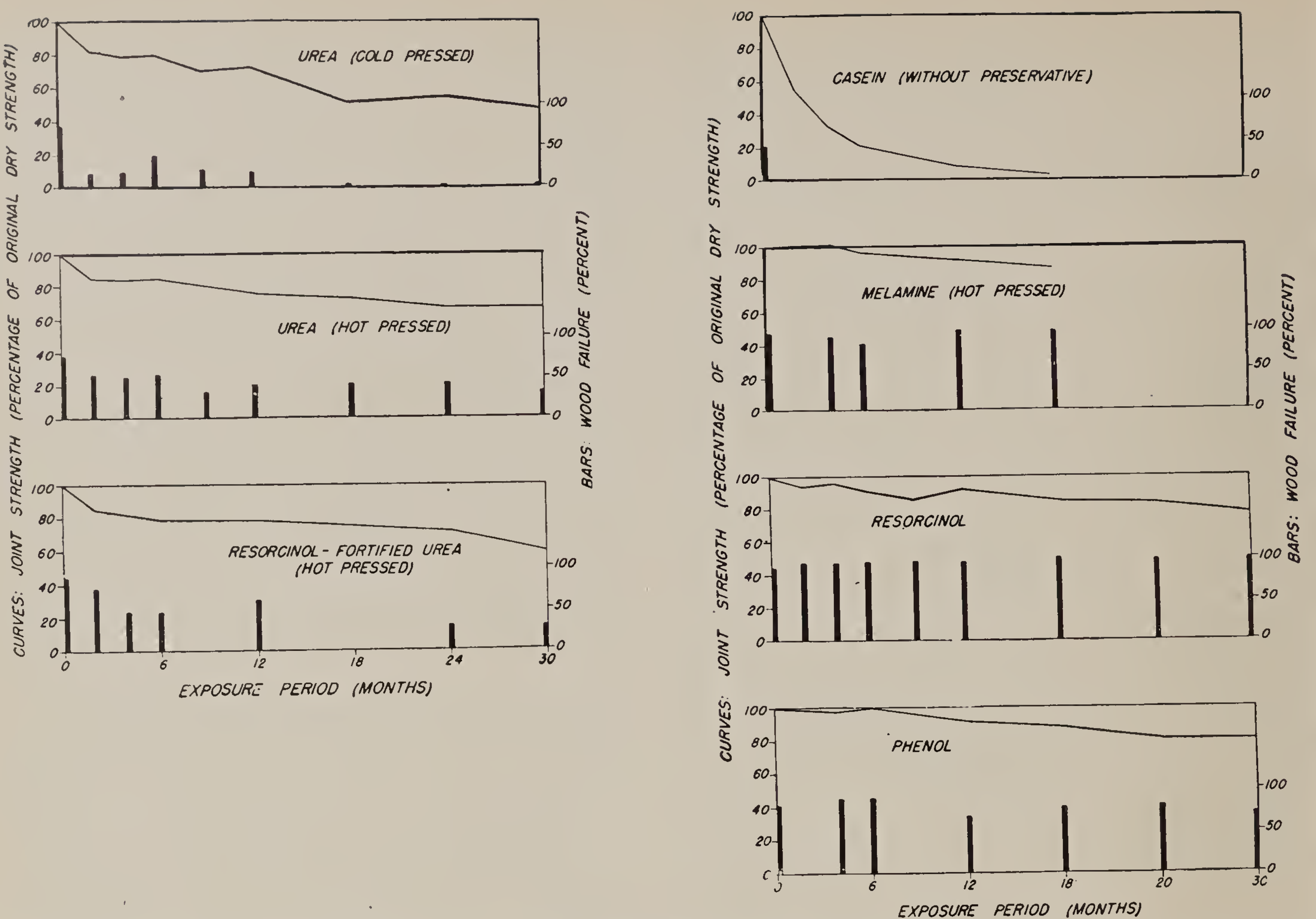

FIGURE 11–2.—Resistance of yellow birch plywood, glued with 7 types of glues, when exposed to a repeating cycle of 2 days' soaking in water at room temperatures and 12 days' drying at 30 percent relative humidity and 80° F.

moderate trend towards reduced strength and wood-failure values under these conditions. The phenol, melamine, melamine-fortified urea, and resorcinol resins, as well as casein, although gradually declining in strength, retained approximately the same percentage of wood failure throughout the exposure period.

Plywood specimens glued with the types of glues shown in figure 11–3 were also exposed to other temperature conditions *(11–1, 11–4)*. When exposed continuously at 158° F., the urea resins, with the exception of the melamine-fortified ureas, weakened more rapidly than is shown in figure 11–3. At 200° F., deterioration was extremely rapid. Melamine-fortified urea resins showed considerably less deterioration. Plywood glued with casein, phenol, melamine, and resorcinol glues showed a gradual reduction in strength, particularly at 200° F., but indications are that the deterioration of the wood was responsible. Exposure to the cycle involving room temperature and —67° F. showed no weakening effect over 36 months on any of the glues tested that could be attributed to low temperatures.

In other tests, birch plywood specimens glued with eight types of glues were exposed to 80° F. and 65 percent relative humidity. This may be regarded as a very mild exposure. The cold-press urea-resin joints were the only ones to show a definite decrease in both strength values and percentage of wood failure over the period investigated. Such decreases under these mild conditions cast doubt on the suitability of these glues for use in permanent house construction.

11.24. Effect of Exposure to Weather on Plywood and Laminated Beams.—Results of tests on laminated timbers exposed to weather without protection confirm in general the order of durability of the synthetic resins and of casein

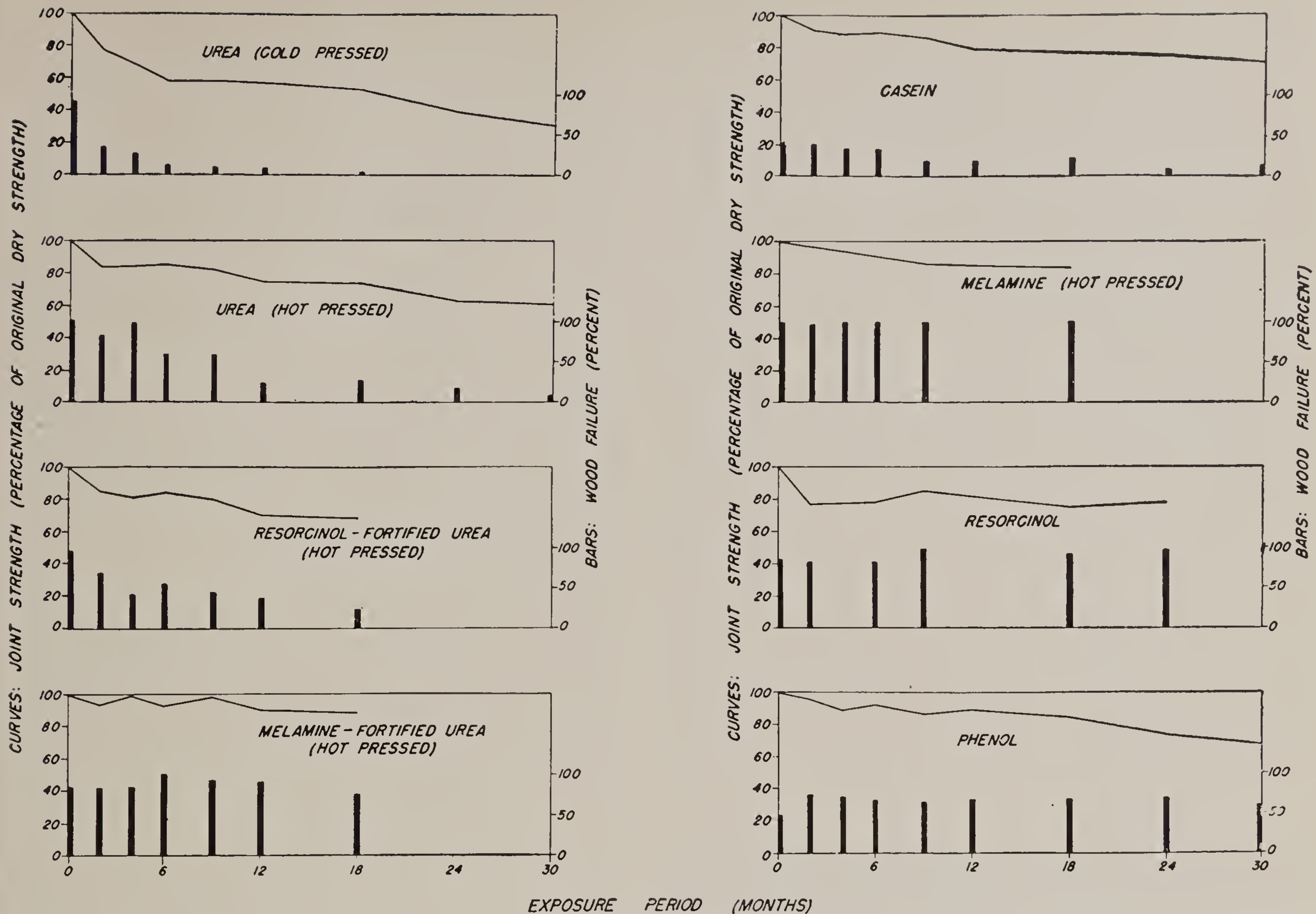

FIGURE 11–3.—Resistance of yellow birch plywood, glued with 8 types of glues, when exposed to a repeating cycle consisting of 8 hours at 158° F. and 20 percent relative humidity, followed by 16 hours at 80° F. and 65 percent relative humidity.

glues as determined in plywood (secs. 11.21 to 11.23).

Tests were made involving the estimation of glue-joint integrity of unprotected plywood panels exposed to the weather at Madison, Wisconsin. The panels glued with hot-setting and intermediate-temperature-setting phenol resins showed a high order of integrity over a period of 84 months. Panels glued with hot-setting and cold-setting urea resins showed appreciable deterioration which continued throughout the period, but this was not so severe as that observed in panels glued with casein without preservative. Panels glued with preserved casein glues were not included in these tests.

11.3. GLUING TECHNIQUES WITH WOOD GLUES.

11.30. Moisture Content of Wood for Gluing.—The drying and conditioning of wood to the proper moisture content for use in prefabricated housing are described in chapter 9. The moisture content of the wood affects the results obtained in gluing and, in turn, is affected by the gluing process. It may be either increased or decreased, depending on (1) the gluing process used, (2) the form and composition of glue, (3) the amount of glue spread, and (4) the dimensions of the glued parts. In general, hot-press methods reduce the moisture content and cold-press processes increase it. Glues of high water content add more moisture to the wood than glues of low water content, and heavy spreads add more than light spreads. More water is added by the glue to a construction of particular thickness made of thin plies than to one made of thick plies. The percentage increase in moisture content from a given amount of glue spread will be greater in woods of low specific gravity than in woods of high specific gravity.

Satisfactory bonds can be obtained over a

fairly wide moisture content range with glues suitable for prefabricated housing. Casein and synthetic-resin glues generally develop the strongest joints when the wood at the time of gluing has a moisture content within the range of 8 to 15 percent. Generally, however, the need for control of the moisture content of the wood will depend more on the service of the assembled structure than on the requirements for obtaining strong glued joints. Changes in moisture content after gluing will develop stresses on the glue joints due to shrinking and swelling of the wood. Consequently, it is of greatest importance that the parts joined be as nearly as possible of the same moisture content at the time the glue is setting, and also that they approximate the average moisture content the product will attain in service (sec. 9.0). The amount of moisture added by synthetic-resin glues having water as solvent is appreciable when relatively thin pieces, such as veneers one-eighth inch or less in thickness, are glued together, but when one-eighth inch plywood is glued to 2-inch stringers the increase in moisture content will be only about 0.5 percent. With casein glue, the wet mix usually contains water in the ratio of 2:1 of the solids content in the glue, and an assembly of one-eighth inch plywood on 2-inch stringers would be increased in moisture content somewhat over 1 percent.

Stresses will also be developed if the interior portion of a member differs greatly in moisture content from the outer portion, or shell. Such differences should not exceed 2 percent.

In prefabrication of houses, gluing is confined essentially to joining of plywood covers to framing members. Hot-pressed plywood, as it leaves the press, is usually too dry for immediate assembling into prefabricated units, and cold-pressed plywood, when the bundles are opened, is usually too wet for immediate assembly operations. Consequently, conditioning the plywood after gluing to moisture content within a suitable range is generally necessary.

11.31. Machining and Surfacing Wood to be Glued.—Wood should be machined for gluing only after it has been uniformly conditioned to the desired moisture content. Drying and conditioning of stock after it has been machined produce distortion and surface irregularities, which are objectionable from a gluing standpoint. After the surfaces have been prepared for gluing, the material should be handled as little as possible and, preferably, glued within 8 hours.

The quality of the final glue bond is determined to a large degree by the accuracy and care with which the surfacing is done. In order to develop glue joints of maximum strength, all gluing surfaces should be machined smooth and true and should be free from all foreign material, such as crayon marks, oil, dust, or grease spots. Normal wood can best be machined for gluing on planers and jointers equipped with sharp knives in proper adjustment (sec. 10.5). The final cut should be relatively light.

Sanding with coarse grit, tooth planing, or other means of roughening smooth, well-planed surfaces of normal wood before gluing are not recommended. Such treatment of well-planed wood surfaces may result in local irregularities and objectionable rounding of edges. While sanding of planed normal wood surfaces is not recommended, sanding is a valuable aid in improving the gluing characteristics of some other wood surfaces, such as those of resin-impregnated wood or wood that has been compressed by means of exposure to high pressures and temperatures (sec. 3.43).

Wood surfaces that are "glazed" from dull tools or by being pressed excessively against smooth, hard surfaces are often somewhat more difficult to glue than normal wood surfaces. Glazing results from crushing or compressing the surface fibers so that they appear glossy. The gluing of glazed surfaces can be improved by light sanding (sec. 10.15) to remove the crushed fibers, or by the application of water, which tends to restore the surface fibers to their original condition.

Plywood surfaces may present more difficult gluing problems than do freshly planed wood surfaces. During the manufacture of plywood, unfavorable surface conditions occasionally develop that interfere with adhesion of glue in secondary gluing operations *(11–2)*. Some of the surface changes that occur in plywood manufacture and that may interfere with the adhesion of the glue in secondary gluing, such as glazing and heavy "bleed-through" of glue, are readily recognized. Bleed-through of glue

is most often encountered on thin-faced plywood of porous woods, such as birch and mahogany.

In contrast to these readily recognized surface conditions, wax deposits from cauls during hot pressing produce unfavorable gluing surfaces that are not easily detected.

Occasionally plywood may be used that has been "presealed" or "toxic dipped" in a water-repellent preservative. Its surfaces may or may not produce satisfactory secondary gluing for stressed-skin construction. Light sanding with fine sandpaper may be necessary along glue-joint areas to insure good gluing surfaces.

11.32. Preparation of Glues for Use.—Glues suitable for prefabricated housing are usually not furnished ready for use; two or more ingredients must be mixed before application to the joint surfaces. In mixing, the most important rules are cleanliness and accuracy. The best of glues can be spoiled if contaminated with foreign materials, and the same holds true if the ingredients are mixed in improper proportions. All measurements of materials should be by weight rather than by volume. All containers used for weighing and mixing should be kept scrupulously clean. This is because the various glues set at conditions of acidity or alkalinity peculiar to the respective adhesives. Residues from old batches left on equipment may prevent subsequent batches from setting. This is particularly true if the brand or type of glue has been changed. When brushes are used, a separate one should be employed for each glue.

It is good practice to weigh each ingredient in a separate container. Where the same mixing equipment is used for different types of glue, care must be taken to remove every trace of one glue before another glue is mixed. For small amounts of glue, scales or balances should weigh accurately to a gram. It is usually expedient to have the tare weights marked on the outside of containers used for weighing, but these weights should be checked occasionally.

Small amounts of glue may be mixed by hand, but larger batches require a mechanical mixer for best results. Various types of mixers have been used successfully. The dough-type mixer (fig. 11–4), equipped with a mechanism for turning the paddle in a double rotary motion at two or three different speeds, has been used with excellent results for mixing casein and resin glues. The proper paddle speed of a mixer is important, as too rapid stirring may cause splashing and loss of the ingredients and contribute to the development of foam in the glue, and too slow stirring will require excessive mixing time and shorten the usable life of the glue. For the type of mixer shown in figure 11–4, a maximum paddle speed of 60 revolutions per minute is usually satisfactory. Mixing bowls of steel, zinc, copper, brass, or aluminum are suitable for use with approximately neutral glues. Metals other than steel should not be used with highly acid or alkaline glues lest the acid or base attack the metals. Mixing bowls should be readily removable from the machine for cleaning. In warm weather, a water-jacketed pot may be used to cool the glue mixture and maintain a sufficient working life. This may also be accomplished by setting the mixing pot in cold water. Some means of cooling is especially important with certain resin glues that heat up during mixing.

Figure 11–4.—Three-speed, dough-type, electric mixer equipped with 3- and 8-quart bowls and two sizes of paddles for mixing glue.

When mixing glue, the manufacturer's instructions should always be closely followed. For most prepared casein glues, the proper amount of water should first be placed in the mixer and the glue powder sprinkled or sifted in gradually, with the paddle in slow motion.

The dry powder is mixed thoroughly with the water and stirred until it is uniformly distributed. It is usually recommended that initial mixing be continued only 3 to 5 minutes. The glue is allowed to rest without agitation for 15 to 20 minutes and then again mixed for 3 to 5 minutes before it is used. Several casein glues thicken and set to a stiff paste during or shortly after the original mixing, but return to workable consistencies during the rest period. This original thickening is normal for these glues and not an indication that additional water is needed.

For urea resins supplied in powder form, the most generally applicable procedure for mixing is to place about two-thirds of the required water in the mixing bowl, add the powder gradually with slow stirring, allow the mass to mix until smooth and free from lumps, and then slowly add the remainder of the water. Stirring is then continued for a few minutes until the mixture is of uniform consistency throughout.

With melamine resins, a procedure similar to that for ureas may be used.

With powdered glues that are likely to become lumpy during mixing, it is usually helpful to mix the glue rather thick at first and then gradually add the remaining water or solvent after a homogeneous mixture has been obtained.

When mixing glues furnished in liquid form, such as resorcinols or intermediate-temperature-setting phenols, it is usually most convenient to place the resin in the mixing bowl and add the powdered hardener with slow stirring. Rapid stirring at the start is apt to cause loss of hardener. After the hardener is completely submerged in the resin, stirring may be more rapid. A total mixing time of 3 to 10 minutes is usually sufficient for these types of glues. A similar procedure may be used when both resin and hardener are liquids. All liquid-resin glues and liquid hardeners should be thoroughly stirred before use to assure uniformity, inasmuch as there may be some segregation of constituents during shipment.

11.33. Working Life of Glues.—As a glue stands in the pot after mixing it gradually increases in viscosity until it can no longer be spread. The working life of a glue is the length of time it remains in a spreadable condition after mixing. This change in consistency is the result of chemical reaction and loss of solvent due to evaporation. The rate at which the chemical reaction proceeds for a thermosetting glue is speeded by increase in temperature. Consequently, it will have a shorter working life if the temperature is high or a longer working life if it is kept cool until spread on the wood.

Different glue formulations within the same type may have considerably different working lives. Room - temperature - setting urea - resin glues commonly have a usable life of from 2 to 5 hours at 75° F. This type of glue gels after the working life is exceeded. As a rough approximation, an increase of about 10° F. in the temperature of the glue solution will reduce the working life of this type of glue by one-half.

Casein glues commonly have working lives of from 5 to 10 hours at 75° F. The effect of temperature on the working life of casein glues is less marked than it is for room-temperature-setting urea-resin glues. As an approximate rule, a rise of some 20° F. at and above room temperature is required to reduce the working life by one-half. In general, it is sufficient to mix casein glue only once during an 8-hour shift in cool weather, and 2 or 3 times during an 8-hour day in hot weather.

The working life of resorcinol glues is usually 4 to 8 hours at 70° F. and about 1 to 2 hours at 90° F. Intermediate-temperature-setting phenols have working lives in about these same ranges. In many glues of these types, the solvent is in part alcohol, and rapid thickening due to evaporation occurs when the glues are constantly agitated. It is therefore not advisable to permit spreaders to run for appreciable periods when not in use. In general, a resin adhesive is usable as long as it flows freely and can be spread properly. When resin adhesives become difficult to spread, they have exceeded their working life and should be discarded.

The temperature changes involved under average operating conditions do not materially affect the working life of most hot-setting phenols. These glues will thicken appreciably, however, in the glue pot and on mechanical spreaders because of evaporation of solvent. This is particularly likely to happen in warm rooms.

11.34. Spreading of Glue.—To make satisfactory glue joints, it is necessary to apply the correct

FIGURE 11–5.—Passing a panel frame through a gluespreader preliminary to fixing the plywood in place.

amount of glue and to spread this glue evenly over the joint areas. With certain glues, this should be done within as short a time as possible. These requirements can usually be most easily met by machine spreading (fig. 11–5). Hand-operated glue guns are often used to apply glue to long, narrow surfaces, such as edges of a stud. Care should be taken not to cant the wheel of the gun. Enough glue should be deposited to give some squeeze-out under pressure.

Spreading by brush is usually satisfactory where small areas are involved or in site-assembly work, but is time-consuming and less adaptable to close control for large areas than is mechanical spreading. For glues of high viscosity and alkalinity, such as the casein glues, Tampico-fiber brushes are preferable to soft-bristle brushes; the latter are most satisfactory for approximately neutral glues that are low in viscosity.

Application of glue to only one of the mating surfaces of a joint (commonly referred to as single spreading) is usually satisfactory for most types of work; however, under certain unfavorable conditions of gluing, such as long assembly periods, or the gluing of scarf joints or excessively sloping surfaces, double spreading should be used. When single spreading is employed, the joint surfaces must be brought together in ample time to insure adequate and complete wetting of the uncoated surface. For most gluing operations in which single spreading is employed, the following spreads of wet glue mixture are recommended:

Glue	*Lb. per 1,000 sq. ft. joint area*
Casein	65 to 95
Resin	45 to 65

Porous woods usually require a heavier spread than do dense, nonporous woods. When both contact surfaces are spread with glue, the total amount applied should be approximately

25 percent more than is recommended for single spreading.

The amount of glue applied is usually expressed in pounds per 1,000 square feet of joint area. It can be determined by weighing a board or piece of lumber of convenient size both before and after glue has been spread on it, dividing the weight of the glue by the area spread, and multiplying by 1,000. In order to maintain uniformity, it is recommended that the spread be checked regularly.

11.35. Assembly Time.—The period between spreading the glue and applying full gluing pressure is called assembly time. If pieces of wood are coated with glue and exposed freely to the air, a more rapid change in consistency of the glue occurs than if the pieces are laid together as soon as the glue has been spread. The condition of free exposure is conveniently referred to as "open assembly" and the condition in which the surfaces are together as "closed assembly." Since the setting action of glue and evaporation of solvent are accelerated by heat, the permissible assembly time will vary with the gluing temperature. At higher temperatures a shorter assembly time is required, whereas at low temperatures a longer assembly time may be allowed. The permissible assembly time is also affected by the age of the glue in the pot. Freshly mixed glue in general permits a longer assembly time than glue that is approaching the end of its working life. High pressures will permit somewhat longer assembly periods than low pressures. Proper regulation of the assembly period is important, since application of pressure too late, and in some cases too soon, may result in unsatisfactory bonds.

For casein glues and room-temperature-setting urea-resin glues, maximum permissible assembly periods are usually about 20 to 30 minutes at 70° F. when the assembly is closed. The maximum open assembly for these glues is commonly about one-half the closed assembly period. There is no minimum requirement for assembly time with these glues.

With resorcinol glues, closed assembly periods of less than 10 minutes or open assembly periods less than 5 minutes have been found to be less satisfactory than somewhat longer assembly times when gluing dense species such as hard maple. When resorcinols are used on softwoods, there is usually no lower limit on assembly time. The upper limit is generally about an hour at 70° F. in closed assembly and about 12 minutes in open assembly.

Intermediate-temperature-setting phenols in general permit considerably longer assembly periods than do the resorcinols, up to 60 minutes in open and up to 120 minutes in closed assembly at 70° F.

Permissible assembly periods for hot-setting phenols vary greatly and may range from 20 minutes to several days. Manufacturers' instructions should be followed for any specific adhesive.

11.36. Gluing Pressure.—The application of adequate and uniformly distributed gluing pressure is essential to the production of consistently good glue bonds. The functions of pressure include smoothing the glue to form a continuous, uniformly thin film between the wood layers, bringing the wood surfaces into intimate contact with the glue, and holding them in this position while the glue sets. Various means of applying gluing pressure are shown in figure 11–6.

Glue joints of good quality can usually be obtained by nail gluing, but the use of a press or other mechanical device for applying positive and uniform gluing pressure is more desirable. Nail pressure is especially applicable to low-temperature-setting adhesives, but can be used with some intermediate-temperature-setting glues if the gluing room is maintained at 75° to 80° F. or higher throughout the curing period. For best results with this method, the nails should have adequate holding power to keep the parts together and be spaced not more than 5 inches apart when using 3/8-inch plywood and 3 inches apart when using 1/4-inch plywood. When nail gluing is employed, the sections fabricated should be stacked immediately after gluing and permitted to remain undisturbed until the glue has set.

Hydraulic pressure may be used whether the glue sets at room temperature or requires heat for curing. Where hydraulic presses are used for the initial pressure application with room-setting adhesives that require several hours of bonding pressure, rails and turnbuckles or similar means may be used to maintain the pressure throughout the curing period (fig. 11–7). When room-temperature-setting glues, such as

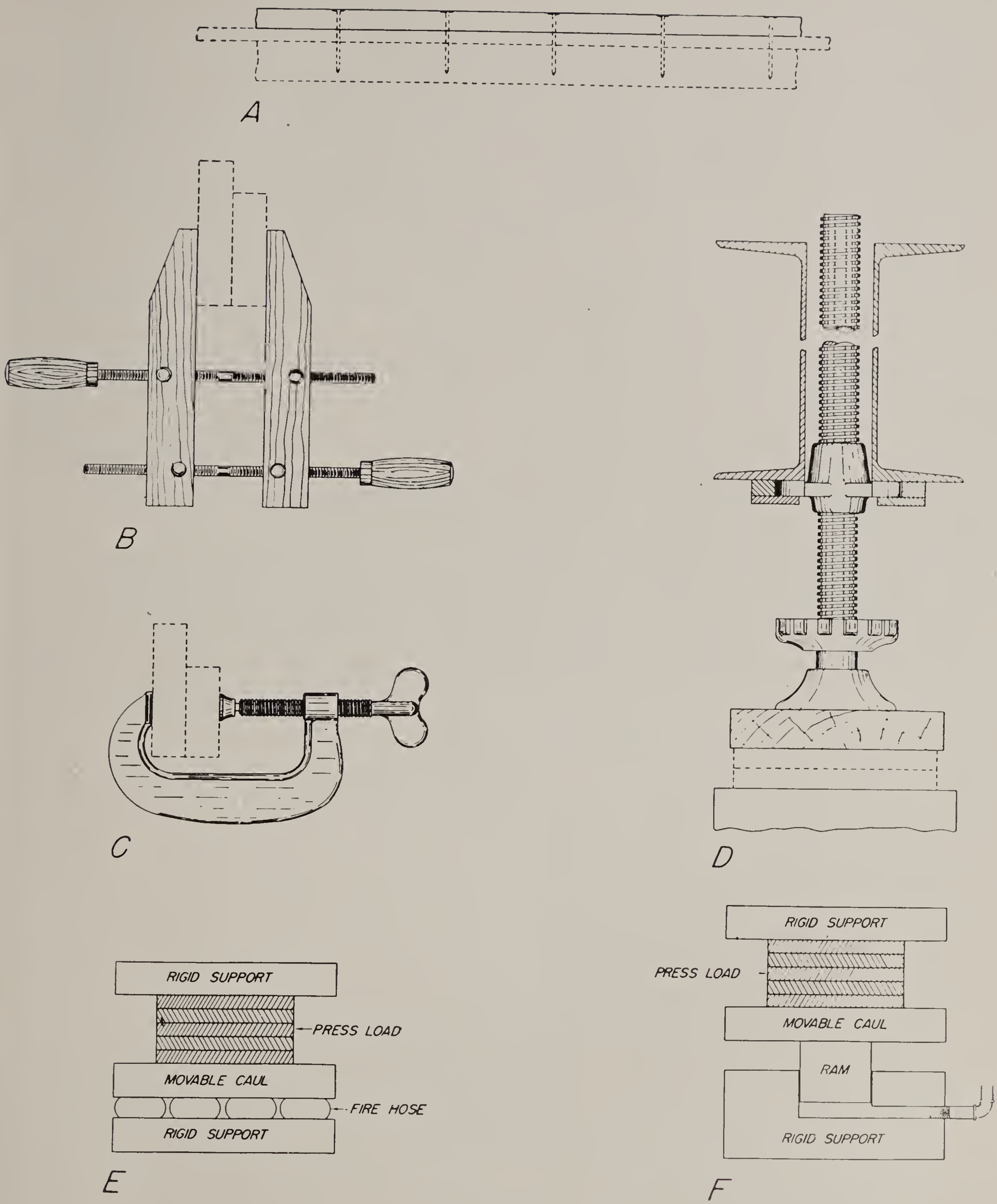

FIGURE 11-6.—Gluing pressure devices. *A*, nails; *B*, wood clamp; *C*, C-clamp; *D*, Jackscrew press; *E*, firehose press; *F*, hydraulic press.

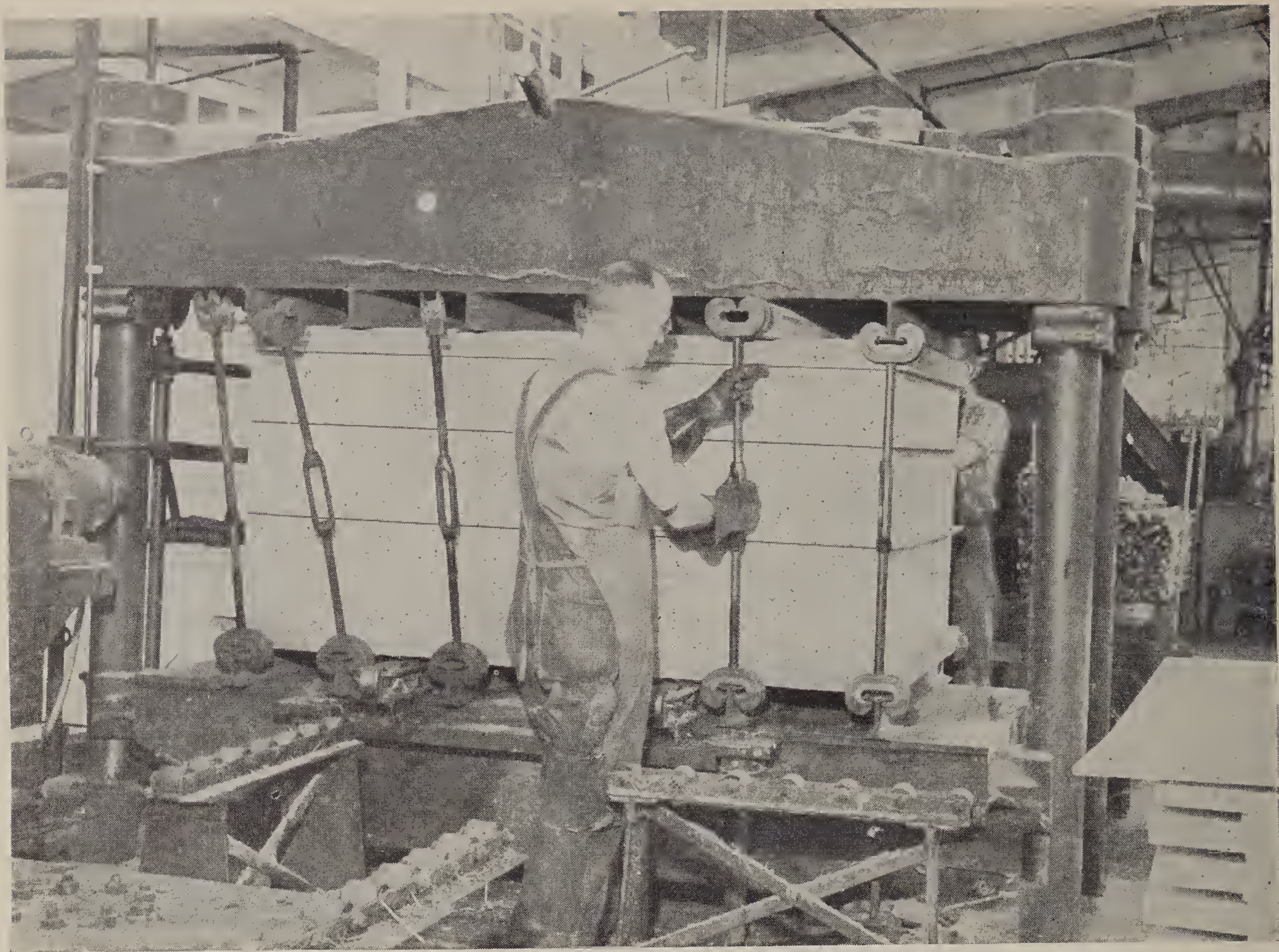

FIGURE 11–7.—Use of I beams and turnbuckle clamps to maintain pressure on glued panels after removal from press where initial pressure was applied.

casein, urea, or resorcinol resins, are used at a temperature of about 70° F., the pressure should be maintained for at least 4 hours. With glues requiring elevated temperatures for setting, multiple-opening hot presses with heated platens, or special jigs or presses heated with high-frequency dielectric current (sec. 11.372), are used for producing sections of prefabricated houses. In hot-pressing operations, the pressing period may range from a few minutes to one-half hour or more, depending on thickness of material, temperature, and kind of wood and glue.

Wood species of high crushing strength require and withstand higher gluing pressure than woods of low strength. The minimum pressure permissible for any gluing operation is one that will insure close contact of the wood surfaces and hold the parts in close contact until the glue has set. Insufficient pressure and poorly machined wood surfaces result in the production of objectionably thick glue lines and joints of inferior quality. The absence of squeeze-out at the joint edge may indicate insufficient pressure if other factors, such as amount of glue spread and assembly time, are suitable.

11.37. Curing of Glue Joints.—The transition from liquid form, in which glues generally are applied, to the solid state, in which they act as bonding agents, is usually referred to as setting or curing. Some of the glues suitable for prefabricated housing will set satisfactorily at room conditions, while others require heat to effect their cure. Among means of furnishing elevated curing temperatures are hot presses, heated chambers, and high-frequency dielectric heating. Proper curing of the glue while the joint is under pressure is essential for strong and durable bonds, regardless of the type of glue used.

11.370. Curing at Room Temperature.—Among adhesives that cure at room temperature are the casein, urea, and resorcinol-resin glues (sec. 11–1). The rate of setting and increase in joint strength of a glue are largely dependent on temperature. With both casein and cold-setting resins, the initial thickening that governs the assembly period is due largely to loss of water or other solvent, but the final setting and the development of the strength and water resistance of the joint depend also on chemical changes in the glue, and both the chemical changes and diffusion of water into the wood are accelerated when the temperature is increased. American-made room-setting urea-resin glues do not set satisfactorily at temperatures below 70° F., and they should not be used on wood or in rooms at lower temperatures. Casein and resorcinol-resin glues, on the other hand, will set at temperatures as low as 40° F., but their rate of setting is greatly slowed and their ultimate joint strength may never go so high as it will at 70° F. A minimum pressing period of 4 hours is generally suitable at 70° F. both for casein and cold-setting resin glues, although a longer period may sometimes be necessary. When gluing with casein or resorcinol-resin glues at temperatures lower than 70° F., the pressing period should be greatly increased as the temperature decreases; in no case should the pressure be removed until the glue squeeze-out has become hard or at least reached the consistency of hard rubber.

11.371. Curing at Elevated Temperatures.—Elevated temperatures are utilized for the hot pressing of flat plywood, to glue plywood to framing members, and, in numerous assembly-gluing operations, to cure the glue in the shortest practical time. In these operations, the glues are spread and the assemblies laid up at ordinary room temperatures but later heated by being placed in heated rooms or chambers

FIGURE 11–8.—Placing a clamped stack of panels in a curing chamber heated to effect rapid setting of glue.

(fig. 11–8), hot presses, a high-frequency electrical field (sec. 11.372), or special assembly jigs heated by steam, hot air, electricity, or other means. All such operations involve the problem of heat transfer through the wood to the glue line as well as the temperature and time required to cure the glue properly. In all assembly-gluing operations carried on in rooms at elevated temperatures, provision should be made to prevent excessive drying of wood during the heating period. Proper humidification is essential if assemblies are placed in heated rooms or chambers to accelerate or effect the cure of glues.

The time-temperature requirements for curing vary for different classes of glues and for individual glues of the same type. The glue manufacturer's recommendations should be followed and checked by thermocouple measurements of the temperatures obtained in each glue joint and by joint tests on each glue line in the assembly to see that all joints are receiving sufficient heat to cure effectively.

High temperatures required for curing hot-setting phenols may cause distortion of prefabricated sections. Glues such as the intermediate-temperature-setting phenols may be more suitable, therefore, than hot-setting glues when plywood is glued to framing in a hot press. The setting time of urea and resorcinol resins, which is several hours at room temperature, may be reduced to a few minutes when curing is done in a hot press. The rate of setting of casein glue is accelerated at elevated temperatures, but to a lesser extent than is the case with ureas and resorcinols.

11.372. High-frequency Dielectric Heating.—If wood is placed in an electric field that oscillates at the frequencies used in the shortwave broadcasting range or higher, heating occurs throughout the mass, thus making it possible to introduce heat at a rate dependent on the material to be heated and the power capacity of the equipment available. The advantage of this method in contrast to heating by conduction is obvious. Further, if the electric field is applied parallel to a glue line containing water, the glue line can be heated selectively without materially increasing the temperature of the wood adjacent to it.

Although this method has been introduced only within the last 4 or 5 years in the United States, it is gaining favor for the rapid setting of the class of adhesives that set at room or slightly higher temperatures. It is applicable whenever a large quantity of a single item is required or when the object to be heated is thick and cannot be heated readily by conduction. The method is being used in a few prefabricating plants to cure room-setting glues rapidly in panels.

11.3720. Methods of Applying Energy.—High-frequency dielectric heating apparatus is similar to that used in shortwave broadcasting, except that, instead of radiating the energy into space, the equipment is so designed that the energy is converted into heat within the

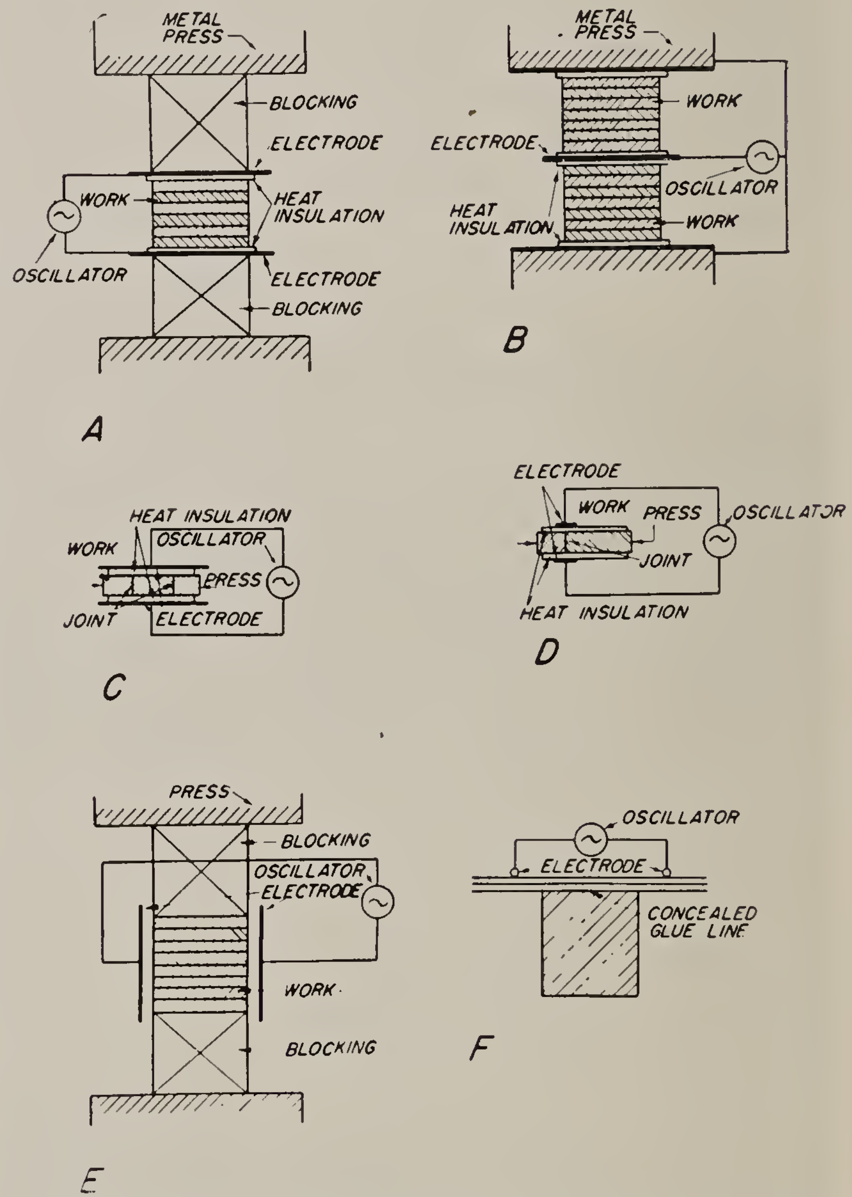

FIGURE 11–9.—Various electrode arrangements for applying high-frequency electrical energy to several types of loads. *A*, work between electrodes, with electric field perpendicular to plane of glue joints; *B*, "sandwich" method, center electrode between two stacks of material; *C*, arrangement for setting glue lines selectively with glue-joint plane parallel to electric field; *D*, narrow electrode for selective glue-line curing when joint is always in one place; *E*, electrode arrangement for selective setting of glue lines in press as in *A*; *F*, "stray-field" arrangement.

mass of the wood occupying space traversed by the high-frequency field. The function of the high-frequency generator is to convert commercial electric power at low frequencies to power at frequencies varying from one to thirty million cycles per second and employing much higher voltages. Units having output up to about 10 kilowatts can be mounted on casters to serve several presses or jigs. Several methods of applying the electric field for the gluing of wood are in use (fig. 11–9).

If a metal press is used and there is sufficient opening, the arrangement shown in figure 11–9, *A*, may be used, but there must be sufficient room for blocking between the press platens and the electrodes to prevent excessive energy losses to the press. When the opening of the press is small, the arrangement shown in figure 11–9, *B*, may be used; in this case two blocks are glued at the same time. By either method, the high-frequency field is applied perpendicular to the plane of the glue joints and the entire mass of material is heated. The method shown in figure 11–9, *B*, is commonly termed the "sandwich" method, because the center electrode is placed between two stacks of material to be heated.

In certain cases, glue lines may be set selectively and very rapidly by applying the electric field parallel to the glue joints. The method is commonly called glue-line heating. An electrode covering the entire piece is shown in figure 11–9, *C*, and is used when the joint may occur anywhere in the width of the glued-up section or, in other words, if the sections making up the pieces are of random widths. A narrow electrode, as shown in figure 11–9, *D*, may be used if a joint is always located in one position. Large assemblies may be heated with the electric field parallel with the glue line where such an electrode arrangement is an advantage, as shown in *E*, but it is probable that little or no advantage in energy savings will result.

Glue lines that are not in direct line with the electrodes may also be heated by high-frequency fields, as illustrated in figure 11–9, *F*. This method has been termed "stray-field heating," and the arrangement is being used in the manufacture of built-up parts for prefabricated houses.

In using either the glue-line or stray-field method with glues containing some water, the electric field is concentrated largely in the glue line, and the wood adjacent to it is not heated appreciably unless the heating period is prolonged. The glue-line method is obviously economical because of the relatively small amount of electrical energy needed. The time needed is generally less than 3 minutes. The practical limits of distance through which the electric field may be applied successfully have not been determined, but the method would be most practical if used on glue lines 3 inches or less in width.

11.3721. Glues Used for High-frequency Gluing.—Urea and resorcinol glues have been effectively used. Phenol-resin glues that require an extended curing period are not suitable for short heating periods. The phenol type of glue appears to be more subject to burns than the other types of resin adhesives.

11.3722. Stray-field Heating for House Panels.—Stray-field heating is particularly well adapted to prefabricated wall panels in which it is necessary to attach the face panels to the in-

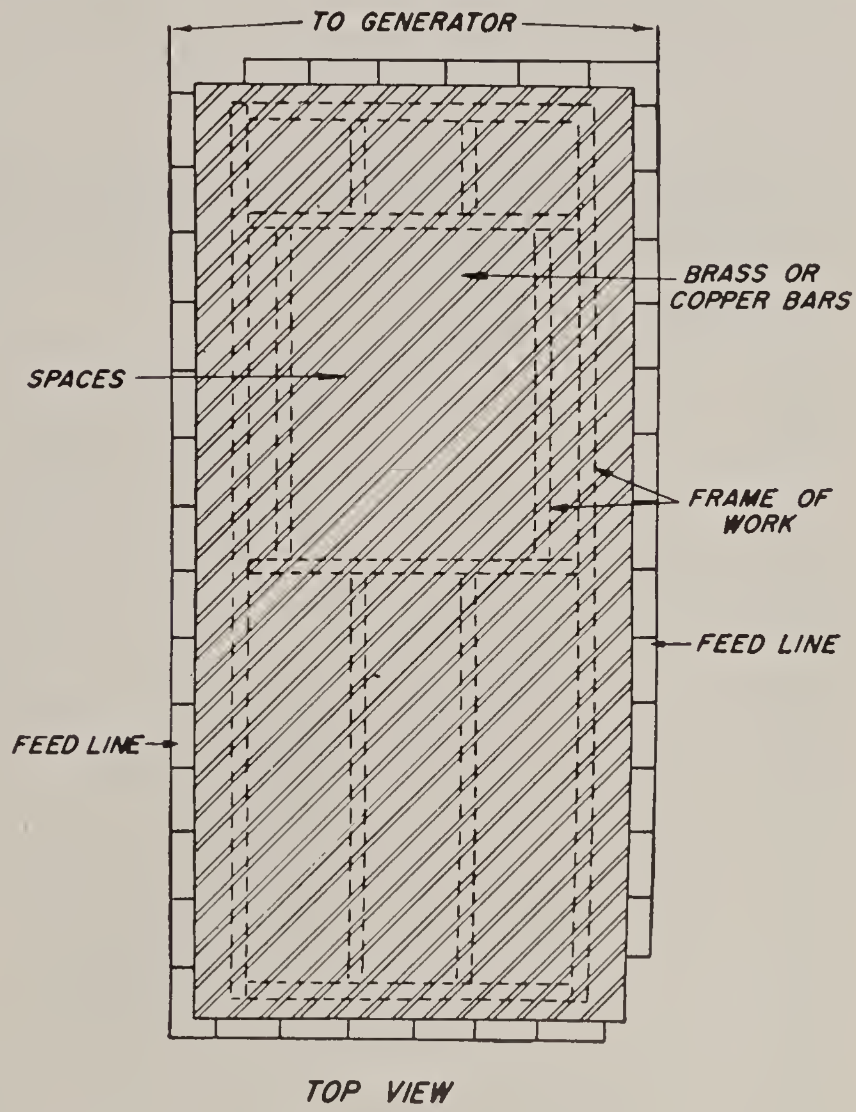

FIGURE 11–10.—Universal electrode for spot gluing by the stray-field method. Lower electrode shown; upper electrode similar.

ternal frames with glue. It is generally desired to attach both the inside and outside covers at one time, which makes it impossible to apply the energy in a direct line with the glue joints.

If a glue that sets at room temperature is used, stray-field heating can be used economically to set the glue at regular intervals along the glue line. These areas act as clamps and hold together the parts to be glued until the intervening spaces have time to set at room temperatures. Such an arrangement is shown in figure 11–10.

The arrangement shown in figure 11–10 might well be called a universal electrode, since the covers can be applied to almost any kind of a substructure, including a regular wall panel, a door, or a window frame. The frame is fastened together, the glue is spread on both sides of the frame, and the faces are tacked on at about six points with small brads. The heads of the brads are counter-sunk to avoid contact with the electrodes. The field is applied between adjacent bars and affects only the glue-line area between them. The press using this electrode is shown in figure 11–11. The generator is at the left of the photograph. Another press using stray-field heating is shown in figure 11–12. In this case the edges of the electrodes are parallel to the joints and the entire area of the glue line is set during the application of the high-frequency electrical energy.

11.3723. Limitations of Method.—Experimental work carried on by the Forest Products Laboratory indicates that satisfactory results can be obtained with stray-field heating through cover plates up to three-fourths inch in thickness. There seems to be a greater loss of energy in the cover plates as their thickness increases.

No difficulty has been encountered with burns in the glue lines being cured, but instances have occurred where the glue in the plywood covers has produced burns. These have usually occurred where accumulations of glue have been present between sections of the core or crossbands that did not fit closely together. The only remedy known is to reduce the voltage being applied.

High moisture content of the covers of the panels has also caused burns. In one instance the plywood panels had reabsorbed moisture around the edges after manufacture, and burns occurred at the ends of the covers where the

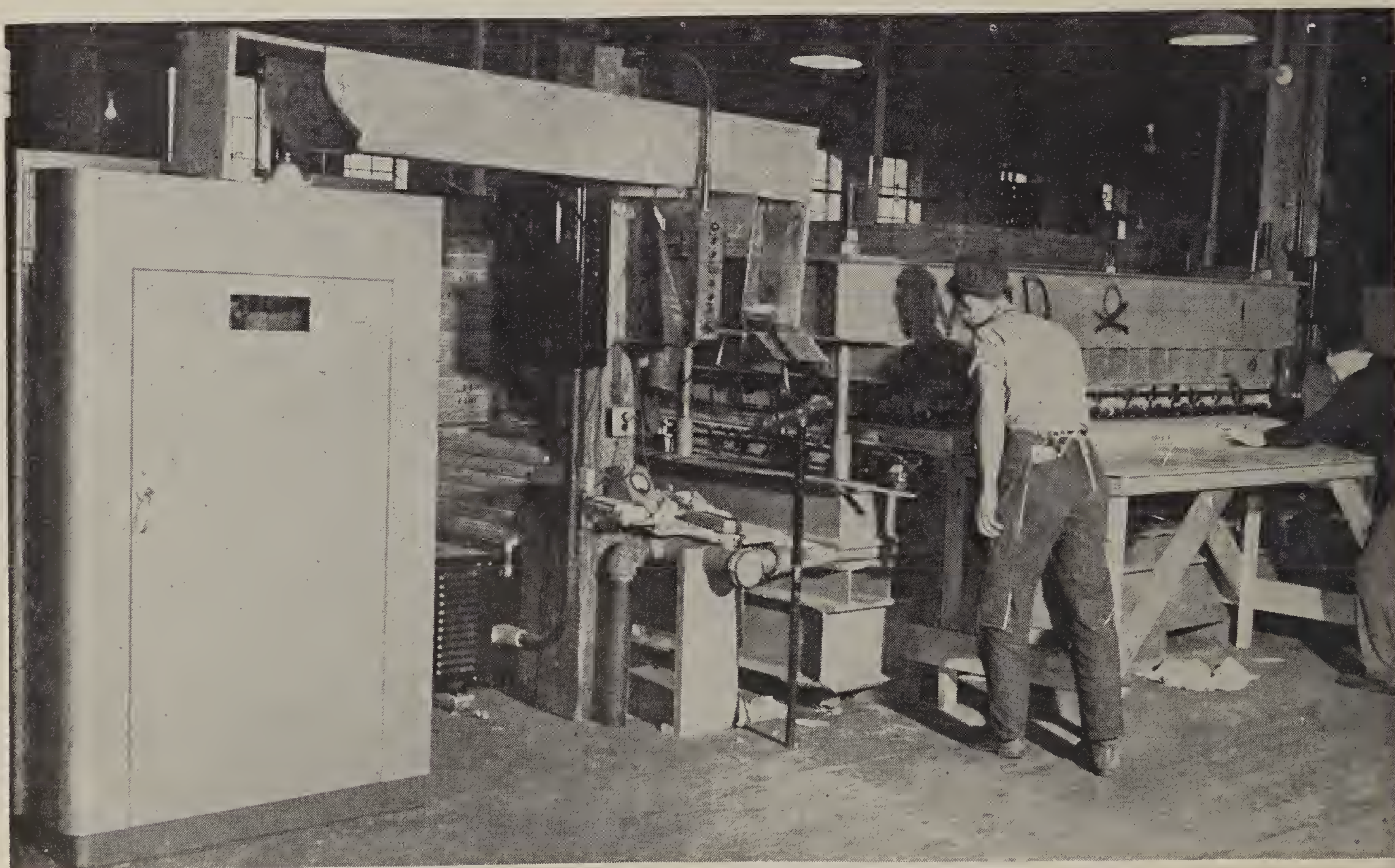

FIGURE 11–11.—High-frequency generator and panel press using diagonal electrodes.

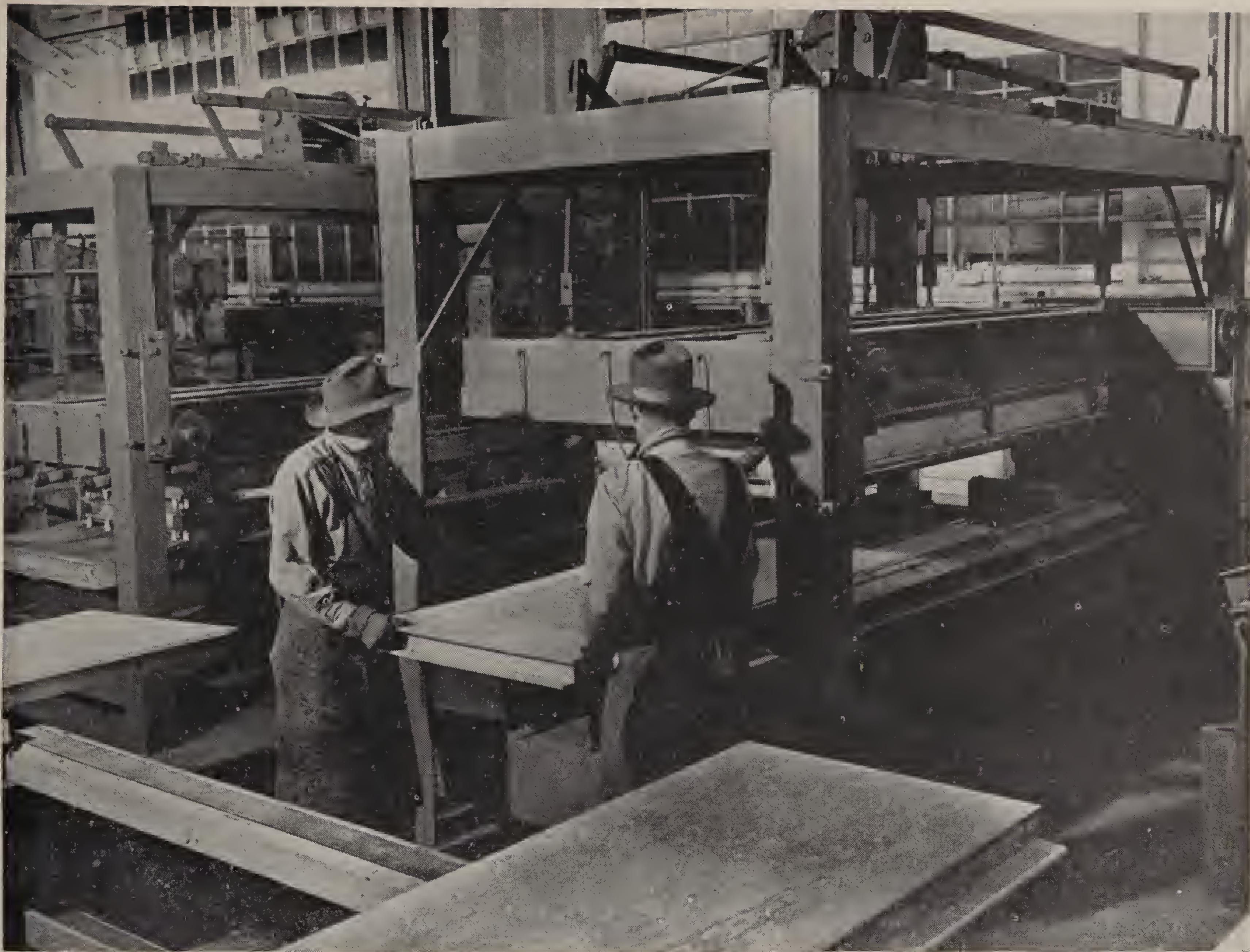

FIGURE 11–12.—Press utilizing high-frequency dielectric heating for setting glues in wall panels.

moisture content was highest. Uniformly dry material should correct such difficulties.

Workers should be protected from injury by guards or signal lights; fluorescent lamps, no longer usable for lighting service, may be hung near the electrodes as indicators. These lamps glow when the electric field is active without any direct connection. Contact with or close proximity to the electrodes or transmission lines causes burns, but not electric shock. The greatest possibility of serious injury is from contact with the high-voltage, direct-current supply to the plates of the power oscillator tubes. Safety switches or interlocks should be provided on all openings to generator cabinets, so that the circuits are open when access doors are not tightly shut. These switches should never be closed with clamps so as to keep the power on while working on or making adjustments to the generating equipment. The only serious injuries to personnel have occurred when this safety precaution was disregarded. As a further safety measure it is recommended that the power connections be separated when adjustments are being made inside the generator cabinet. Provision should be made to discharge or ground condensers used in the generator before contact is made with any of the conductors in the generator. Condensers may hold a residual electric charge for some time after the power is cut off and may cause electric shock injury if a worker should make contact with the conductors from the condenser. Leakage resistances are usually provided to discharge condensers, but they should not be relied on to prevent electric shock injury. A grounding connection should be provided for the use of the operator before handling conductors within the generator housing.

11.373. Conditioning After Gluing.—After pressure has been released, a conditioning period is usually required to allow time for the moisture absorbed by the wood from the glue to distribute itself throughout the piece, as well as to permit completion of the setting reaction. With room-setting glues, a conditioning period of from 3 days to a week is usually satisfactory, depending upon the species and thickness of the material glued. For woods that permit rapid distribution of moisture, the shorter periods should suffice under most conditions. In assembly gluing of prefabricated housing sections, usually no member less than one-fourth inch in thickness is involved, and the increase in moisture content due to gluing will not be appreciable. Consequently, 3 to 4 days of conditioning should be satisfactory. When such sections are glued in a hot press, the moisture content will be reduced somewhat. With glues requiring moderate cures, however, this reduction will not be appreciable, and a conditioning period of sufficient duration to cool the sections is usually satisfactory.

11.38. Gluing of Wood Treated with Preservatives.—Only limited information is available on gluing of wood previously treated with wood-preserving chemicals. Results of investigations indicate, however, that glue bonds adequate for house construction can be obtained with various types of glues in wood treated with certain preservatives, such as chlorinated phenols and copper naphthenate, when the treating solutions are prepared with volatile solvents, but that the technique used for gluing untreated material may not always be adequate for treated wood. It was found, for instance, that higher curing temperatures were required when gluing treated than untreated lumber when using an intermediate-temperature-setting phenol-resin glue, and that higher curing temperatures possibly are necessary also when using resorcinol glues.

Marked interference with adhesion was found in material treated with water repellents and sealers.

Oil-borne preservatives (sec. 6.20) often leave a deposit on the surface of the lumber which interferes with the development of good glue bonds even though the lumber was smoothly surfaced before the preservative was applied. Resurfacing of the lumber after treatment removes this deposit, thus reducing the interference with gluing, but also removes the most thoroughly protected part of the wood. Some woods treated with oily preservatives, moreover, may "bleed" preservative even on freshly machined faces, which continues to interfere with the development of good glue bonds.

Results of tests show, however, that adequate bonds can be obtained with many preservative-glue combinations when the retention of oil is not high enough to cause "bleeding." Just as gluability of treated lumber can be improved by resurfacing, light sanding of plywood and framing members treated with Stoddard solvent solutions of chlorinated phenols improves the quality of glue joints on surfaces that are not satisfactorily glued without sanding.

Treatment with water-borne chemicals necessitates redrying of the lumber, and it is then generally too variable in thickness to be suitable for gluing without resurfacing. When the materials were surfaced immediately before gluing, however, adequate bonds were obtained with some phenol and resorcinol glues in material treated with water-borne preservatives, such as chromated zinc chloride and zinc meta arsenite; somewhat higher curing temperatures were required than for untreated material. Other glue-species-preservative combinations, however, interfere with bonding, and general recommendations for gluing of preservative-treated materials cannot yet be given.

11.39. Glue-joint Quality Tests.—Tests for the quality of glue joints other than those in plywood (sec. 4.11) are usually made by the block-shear method. Figure 11–13 shows the shear-test specimens, shear tool, and testing machine used to conduct block-shear tests.

When the block-shear method is used as a control test, the test material should be glued under conditions identical to those used in production. It is best to allow a conditioning period of about a week before shear specimens are cut and tested, although for factory quality control it may be necessary to test after a shorter period and to set up suitable quality standards accordingly. It is important that the test specimens be of the same moisture content in different tests; otherwise comparable results cannot be obtained. For each specimen tested, a record should be made of the break-

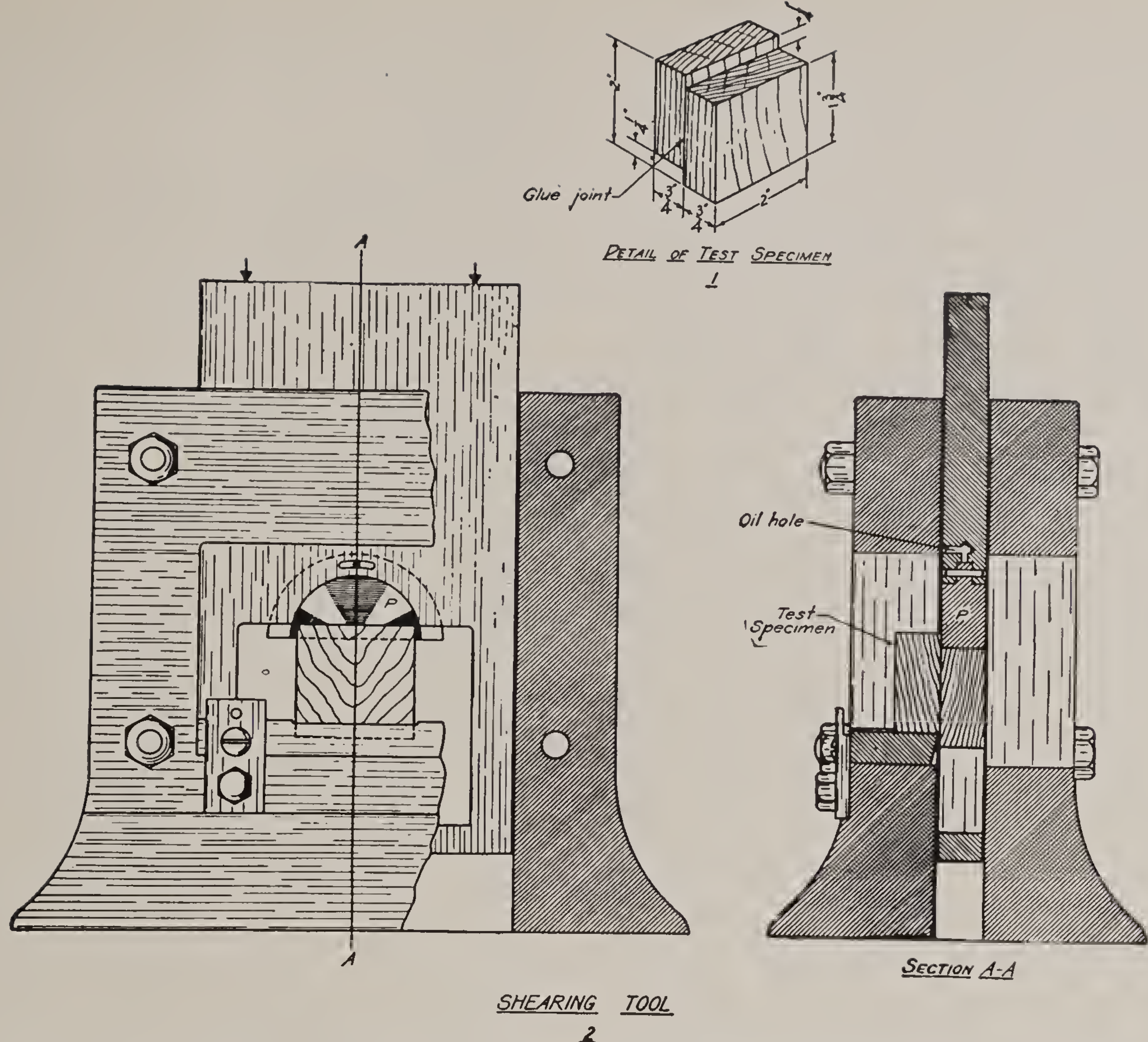

FIGURE 11–13.—Block-shear joint test apparatus. Above, test specimens and shear tool; below, testing machine. This apparatus can be used to test glue joints bonding plywood to solid wood.

ing load and the estimated percentage of wood failure occurring over the glue-joint area. It is the usual practice to express the breaking load in pounds per square inch of glue-joint area and to estimate wood failure in percent of the area sheared.

11.4. GLUING WOOD TO METALS, METAL-FACED SANDWICH PANELS, OR PAPER-BASE PLASTICS.

11.40. Wood-to-Metal Gluing.

11.400. Glues.—The formulation of glues used to bond wood to metal is one of the more recent developments in adhesives. Because of the newness and continued development of the glues for these purposes, the classifications and properties are not so well defined as in the case of glues used for the bonding of wood to wood. The properties are not so well known, nor are so many glues available, as for woodwork gluing.

Information provided by manufacturers concerning the chemical nature of these adhesives is limited. The properties of some of them indicate, however, that they are composed of at least two components, one a thermoplastic and the other thermosetting. Others appear to be a mixture of a rubber component with a thermosetting synthetic-resin component, usually phenol formaldehyde. Polyvinyl resin solutions are also used to a limited extent without thermosetting modification.

A few of these glues are recommended for use at room temperature, but most of them require hot pressing.

11.401. Preparation of Surfaces.—The surfaces of both the wood and metal should be free of wax, grease, dirt, dust, scale, and loose oxides. If the surface condition of the wood is not known, the surface should be lightly sanded with No. 0 sandpaper before the glue is applied. The moisture content of the wood should preferably be between 8 and 12 percent.

Solvent cleaning of the metal with trichlorethylene, ethylene dichloride, acetone, car-

bon tetrachloride, toluol, or solvent naptha, or with a hot alkaline solution containing sodium metasilicate, trisodium phosphate, or soap, is advisable to remove impurities from metal surfaces that do not have scales or loose oxides. The solvent cleaners should be allowed to evaporate completely before application of the glue. The alkaline detergents should be immediately rinsed from the metal upon removal from the cleansing solution. After an alkaline treatment, a mild acid wash is sometimes used in addition to the water rinses.

Scales or oxides can be removed from the metal surfaces by either mechanical or chemical methods. Scouring with solvent-soaked steel wool (No. 0 or 00), brushing with a fine wire (0.002- to 0.003-inch diameter) brush, or sandblasting are mechanical methods that can be employed. These should be followed by degreasing with solvent or detergent cleaners.

The chemical baths that can be used for removing scales and oxides vary with the metal being cleaned. Dilute hydrochloric acid can be used for pickling steel, and frequently this bath is preceded with a sulfuric-nitric acid bath to obtain faster pickling action. There is slight chemical attack of the surfaces of aluminum and magnesium alloys by the hot alkaline detergent solutions, but greater attack has been obtained by the use of a hot 15 percent solution of sodium hydroxide. The preparation of aluminum-alloy surfaces can be done satisfactorily by a 10- to 20-minute immersion at 140° to 150° F. in a bath containing approximately 25 percent sulfuric acid and 3 percent sodium dichromate. In most instances it woud be well to precede the alkali or acid etching treatment with the solvent or detergent cleaning, but the sulfuric-dichromate bath removes grease well enough to be used alone.

In general, care should be taken to remove all solvent and treating chemicals from metal surfaces, inspection should be made to see that no grease remains on the metal as evidenced by breaks of the water film, and the rinsing waters should be dried from the metals as quickly as possible. The glue manufacturer generally recommends surface preparations that he has found to be suitable for his particular glue. No other cleaning method should be used unless it is checked with the results obtained by the recommended methods, as there are some indications that certain types of glue require mechanical or chemical etching of the metal while other types require only degreasing.

11.402. Application of Adhesive.—The application of the glue is dependent on the type of glue and its viscosity. Most of the adhesives as supplied can be applied with a brush, but for large surfaces spray or roller application is more convenient. For some of the room-temperature-setting types of heavy consistency, it is frequently recommended that a saw-tooth scraper be used, but for most adhesives the spread should be as smooth and uniform as possible.

Spraying is generally used for speedy and efficient application of the adhesives. Solvents are either supplied or recommended by most glue manufacturers for thinning the brush-type adhesives to spraying consistency; a thinner can be formulated for most adhesives with the alcohol, ketone, ester, and aromatic solvents. A mixture of two or more solvents may be found to have better solvent and drying properties than any single solvent. Spraying should not be done when the relative humidity is so high that the deposited film "blushes."

Where adhesives are used as a direct bond, either hot- or room-setting, the adhesive should be applied to both the metal and the wood. Where the adhesive is used for metal priming, the special adhesive is applied to the metal only and a second, usually one of the woodworking resin glues, is used for bonding the wood to the primed metal surface. With one direct-bonding adhesive, a dry resin component is added by sprinkling it in powder form on the wet resin that has been applied directly to the metal surface.

The adhesives are generally applied in two to three brush coats or four to six spray coats to obtain a film thickness of 0.002 to 0.003 inch on each surface spread.

11.403. Assembly and Precure Drying of Adhesives.—To obtain the maximum cohesive strength of the glue and to prevent blistering in the glue joint, it is necessary that the solvents be removed from the adhesive coating. For glues used at room temperatures, an open assembly period of 5 to 20 minutes after the last coat has been applied, or until the adhesive is at the "tacky" stage, should be allowed

for solvent removal. For adhesives that are cured at higher temperatures, the open-assembly periods can be from 1 hour to several days, depending upon the thickness of spread, kind of solvent, and type of glue used. In general, the hot-setting glues do not lose adhesive strength because of a 16- to 24-hour open-assembly period, and a period this long is often desirable to remove most of the solvents present.

With many of the hot-setting glues, open assembly at room temperature is not sufficient to remove all solvents. The adhesives on the metal and wood are therefore precured at elevated temperatures following open-assembly air drying. The recommended precuring conditions, depending on the type of glue and solvent, vary from 45 minutes at 140° and 180° F. to 15 minutes at 325° F. Drying ovens can be used for the lower precuring temperatures and hot-press platens for the higher precuring temperatures. Frequently the precuring temperature can be the same as the curing temperature, and in this case the panel may be assembled, placed in the hot press, and precured without pressure before the pressing cycle. Care should be taken in the precuring cycle that the adhesive not be cured beyond the stage where it will flow and form a good joint.

11.404. Curing of Wood-to-metal Joints.—The curing conditions vary considerably among the different glue formulations. In general, the room-temperature-setting glues should be pressed for at least 16 hours at a temperature of 75° F., but nearly all glues of this type can be pressed for shorter periods at higher temperatures. Most hot-setting wood-to-metal glues can be cured within the range of 1 hour at 260° F. to 10 minutes at 340° F., but one group requires a curing temperature of at least 325° F.

The pressures applied while the glue is being cured should be as high as possible without exceeding the allowable pressure for the wood species being bonded. Most of the hot-setting wood-to-metal adhesives do not flow readily during the bonding process unless high pressure is used.

11.405. Gluing with Two-step Metal-priming Process.—A process for obtaining a high-strength glue joint between metal and wood by room-temperature assembly and curing consists of applying the hot-setting special priming adhesive to the metal, as described in section 11.402. After the prescribed assembly period, the adhesive is cured on the metal without pressure. This cured adhesive film is lightly sanded with No. 0 or No. 00 sandpaper to remove any surface irregularities or contamination before the second glue is applied.

11.406. Storage of Wood-to-metal Adhesives.—Because many wood-to-metal adhesives consist of combinations of chemicals that have limited solubility in a common solvent, these adhesives should occasionally be mixed to prevent separation. Cold storage at about 40° F. is recommended for storage periods of more than a month. Most of these adhesives are sensitive to small amounts of moisture. When cans of glue stored at 40° F. are used, therefore, contents should be allowed to warm to room temperatures before opening the can to prevent their being contaminated by moisture condensed from the air. Partially filled cans containing some warm moist air should not be returned to cold storage.

11.407. Quality of Glued Wood-to-metal Joints.—Most of the hot-setting adhesives now marketed for wood-to-metal gluing are capable of making good joints regardless of the wood species being glued. Glues of the room-setting type have not yet been developed to the same degree of glue-joint quality. Bonds made with the room-setting type of glue usually tend to be more flexible than those made with the hot-setting glues. Many of these glues, however, have sufficient strength for most joints of house construction where metal would be bonded to wood, except for those that are highly stressed.

Rather extensive durability studies have been conducted on wood-to-metal joints made with the hot-setting and the two-step primer secondary gluing processes by exposing glued joints to various cycles of humidity and temperature and by soaking them in tap water, oil, gasoline, alcohol, and various other fluids. In general, durability is dependent upon metallic corrosion under conditions of high humidity and water immersion as well as upon the resistance of the particular glue to these conditions. The chemical composition of the glue was found to be important to its durability in the glued joint when soaked in alcohol or gasoline.

11.41. Gluing of Metal-faced Sandwich Constructions.—The glues and gluing procedures for wood-to-metal gluing can generally be utilized for the fabrication of low-density, high-strength panels consisting of metal faces and low-density cores of cellular cellulose acetate, expanded rubber, polystyrene foams, low-density woods, and honeycomb constructions. The glues used for these panels should be hot-setting or two-stage (primary and secondary) glues.

It is necessary, in using the hot-setting type of adhesive, that the glue selected have sufficient flow during the curing cycle so that good adhesive contact will be obtained at the low pressures that necessarily must be used with low-density cores, yet cure sufficiently to have high strength and low creep properties at elevated temperatures.

The two-step gluing processes (sec. 11.405) are used in the fabrication of sandwich panels by priming the metal face with the special adhesive, curing this glue, and then gluing the core to the primed metal face with a room-setting resorcinol or intermediate-temperature-setting phenol glue. Secondary gluing with a wet or "tacky" glue may result in trapping considerable solvent in the panels. With thin panels especially, a high moisture or solvent content may thus develop; for such panels, direct bonding is to be preferred.

11.42. Gluing of Wood to Paper-base Plastic Laminates.—Paper-base plastic laminates can generally be glued to wood with the same glues and gluing conditions that are used for normal wood-to-wood gluing. It has been found necessary, however, to remove the glossy surface of the plastic in order to obtain bonds with room-setting and intermediate-temperature-setting resin glues, and this is desirable with all other types of glues. Sanding is adequate to remove the surface gloss.

When papreg surfaces are sanded, joints with shear strength equal to that of the plastic can be consistently obtained with casein, urea, phenol, and resorcinol glues. Many of the hot-setting glues, especially those containing organic solvents, require sufficient drying during the assembly period to remove practically all solvents; otherwise, blistering and weak joints may result.

In order to bring papreg surfaces into the intimate contact that is required for good gluing, papreg one-fourth inch or more in thickness should be milled to uniform thickness and flatness unless low-density woods and high pressures are being used. When nail gluing papreg of any thickness to wood, the burr formed on the under side of the papreg where pierced by the nail will interfere with uniform contact, and the only satisfactory method known is to prebore the nail holes in the papreg.

Durability tests on glued joints between wood and papreg indicate that glues show the same durability in these joints as they do in normal wood-to-wood joints.

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WOOD AND PLYWOOD FOR SPECIFIC PARTS OF HOUSES

12.0. GENERAL.—Production of houses in volume on an assembly-line basis presupposes the availability of raw materials in quantities and qualities sufficient to permit reasonable freeness from interruption because of shortages. To some extent, the prefabricator can protect himself from such interruptions by keeping several weeks' or months' supply of lumber, plywood, and other materials on hand. Long-range planning, however, requires that he be assured that his sources of supply are themselves reasonably permanent. Without such assurance, production costs could not be maintained at a stable level, developmental work aimed at improvement of his product would be hampered, and the heavy investment in plant and organization necessary for production and sales might be jeopardized.

To a great extent, these considerations govern the prefabricator's choice of wood and plywood species as well as other materials. In a sense, therefore, the properties of the materials used may have to be subordinated. To cite an extreme example, he is not likely to select such an exotic species as African iroko, regardless of how admirable its properties as an interior plywood might be. The needs of his business dictate that he confine his choice of species as a rule to those that are domestically available in quantity. Fortunately, the forests of the United States still possess relatively abundant supplies of woods well suited to the requirements of the prefabricated house. The more important housing woods available in reasonably good quantity are briefly described in chapter 2.

While the prefabricator has available a reasonably wide range of species from which to select those he wishes to use, indiscriminate use of one or another for all purposes is to be guarded against. While many woods can be substituted for one another in particular uses, in other applications certain woods are definitely inferior. Intelligent selection of wood species, therefore, presupposes some knowledge of the properties and characteristics of the species selected. It is to the prefabricator's benefit, in fact, that he plan his procurement program on as flexible a basis as possible consistent with availability and other limitations, so as to make use of a variety of interchangeable species. In this way, he will assure the permanence of his sources of supply by distributing his raw material requirements over as broad an economic area as possible.

The information in this chapter is intended to assist the manufacturer of prefabricated houses in making intelligent selection of the woods he will use in the various parts of his house. No attempt is made to recommend suitable grades of lumber, because of the large number of grading rules in use for different species and the complex nature of the subject. Basic information on grading principles and rules is presented in chapter 4, together with some information on normal use of various grades in specific parts of houses.

12.1. TYPES OF PLYWOOD FOR HOUSE PARTS.

12.10. General.—The basic classification of softwood and hardwood plywood by types and grades is discussed in section 4.1. In selecting the types and grades for use in the various parts of the house, the builder must bear in mind the use requirements for the different parts. In general, these use requirements will determine whether to use a "waterproof" type or one of the moisture-resistant grades. The following discussion of use requirements is intended to assist prefabricators in making the best and most economical use of the various grades of plywood available and to avoid using types and grades that are unsuited for particular uses.

12.11. Wall Panels.

12.110. Exterior, Exposed to Elements.—Only plywood bonded with phenol-resin glues or glues of equal water resistance and durability should be used for exposed exterior wall panels. Such plywood is exposed to severe weathering and moisture conditions and must have the high

resistance to moisture that only the "exterior type" can give. The Sound-One-Side grade of exterior-type plywood (Commercial Standard CS45–45) or its equivalent (Commercial Standard CS 35–47) is usually suitable for exterior exposure with the sound side out.

12.111. Exterior, Covered with Siding.—Plywood made with moisture-resistant glues, such as soybean or casein, is usually suitable for exterior wall panels that are protected from direct exposure to the weather by siding, shingles, or other covering and by suitable moisture barriers. Where service conditions are such that adverse humidity or moisture conditions are likely to be encountered, exterior-type plywood should be used. The sheathing grade is usually satisfactory for this purpose. If there is adequate ventilation the exterior grade is not required.

12.112. Interior with Natural Finish or Painted or Papered Surface.—Moisture-resistant plywood of the wallboard grade is usually suitable for this purpose. The Sound-One-Side grade (Commercial Standard CS45–45), or the equivalent grades and types of hardwood plywood (Commercial Standard CS35–47), which contains fewer defects on the back side, is sometimes preferred when the quality of the back surface is important, as in the gluing of a stressed-cover unit. The face of either grade is suitable for natural or stained finishes and for painting or papering.

12.113. Interior, for Use Under Adverse Moisture Conditions.—Under adverse humidity conditions, such as may occur in kitchens, bathroom, or laundry, plywood made with ordinary moisture-resistant glue would not be expected to be durable even under indoor use, and an exterior type is recommended. Even when well protected with paint, the moisture-resistant type is likely to delaminate when exposed to wide variations in humidity and temperature. Plywood bonded with durable resin glues is required for satisfactory service.

12.12. Floor Panels.

12.120. Top Coverage for Use as Wearing Surface.—Plywood of the denser hardwoods or with dense hardwood faces makes a very satisfactory flooring. Plywood made of rotary-cut softwood veneer does not make the best wearing surface and is likely to separate between annual growth layers and to sliver when used for flooring. Edge-grain veneer produced by slicing does not have this handicap, and plywood made with the top face ply of this type of veneer and the remainder of the panel of rotary-cut veneer has been produced for use as flooring panels.

12.121. Coverage of Under Side Where Exposed to Moisture Hazard.—Exterior-type plywood is most suitable for uses where there is a distinct moisture hazard, as for covering of the lower side of floor panels of basementless houses. Service conditions have shown that moisture-resistant plywood develops serious delamination when exposed to damp or humid conditions, and the use of more moisture-proof types of plywood is strongly recommended.

12.13. Roof Panels.—In dry climates, moisture-resistant types of plywood are ordinarily satisfactory for top coverage of roof panels that are protected with shingles, asphalt paper, or other roofing, although exterior-type plywood would offer far better assurance of durability in case of such moisture hazards as leaks in the roofing. The sheathing grades of plywood are usually satisfactory for top coverage of roof panels.

For bottom plywood of units with stressed coverings moisture-resistant plywood ordinarily serves well. In areas or constructions where condensation can be expected, however, exterior-grade plywood is preferable. Where the moisture-resistant type is used, a wallboard grade would usually be satisfactory for bottom panel covers. Of the exterior type, the Sound-One-Side grade is suitable.

12.2. WOODS USED IN PREFABRICATED HOUSING.—To some extent, the species of woods that are used in prefabricated housing depend upon the type of house being built. The prefabricated nailed house, of course, can be made of the woods commonly used in conventional house construction. The choice of species is somewhat more limited for the builder of stressed-covered houses, because plywood of the qualities needed is produced in volume from relatively few species. In low-cost housing, price also is an important factor.

In general, lumber of the most important construction species is available in most parts of the United States. Geographical distribution of the various species, however, plays a not in-

TABLE 12–1.—*Lumber production of important housing woods in 1939 for all purposes, as reported by the Bureau of the Census*

Species Grown in Eastern United States	Production	Species Grown in Western United States	Production
	M board feet		*M board feet*
Ash	90,000	Douglas-fir	6,494,301
Baldcypress	421,584	Fir, white	97,712
Beech	119,564	Hemlock, Western	(1)
Birch	140,738	Larch, Western	(2)
Hemlock, Eastern	(1)	Maple, bigleaf	(3)
Maple	(3)	Pine, ponderosa	3,360,004
Oak, red and white	1,432,119	Pine, sugar	308,929
Pine, Eastern white	513,702	Pine, Western white	490,560
Pine, Southern yellow	7,749,188	Redcedar, Western	(4)
Spruce, Eastern	(5)	Redwood	345,003
Sweetgum	382,693	Spruce, Sitka	(5)
Tupelo	271,486	White-cedar, Port Orford	(4)
White-cedar	(4)	Yellow-cedar, Alaska	(4)
Yellow-poplar	276,383		

[1] Total production of Eastern, Western, Mountain, and Carolina hemlock reported as 665,259 M board feet.

[2] Total production of Western larch and Eastern larch (tamarack) reported at 111,488 M board feet.

[3] Total production of sugar, silver, and red maple in the Eastern states and of bigleaf maple in Oregon and Washington reported at 445,163 M board feet.

[4] Total production of Western redcedar, Port Orford white-cedar, Alaska yellow-cedar, California incense-cedar, Northern white-cedar, Atlantic white-cedar, and Eastern red-cedar reported at 263,700 M board feet.

[5] Total production of Eastern, Sitka, and Engelmann spruce reported at 346,159 M board feet.

considerable part in the prefabricator's choice of species he will use for many parts of his houses. Roughly, availability based upon geographical distribution occurs about as shown in table 12–1.

How a few woods, notably Douglas-fir, southern yellow pine, oak, and ponderosa pine, predominate in lumber production for all purposes, is shown in table 12–1. These are also our most heavily used woods for housing—Douglas-fir and southern yellow pine for structural lumber, oak for flooring and general millwork, and ponderosa pine the principal millwork softwood. They are also the most heavily used woods on a nationwide basis. In actual use for housing, the other woods are utilized regionally to a greater extent, with such notable exceptions as bald-cypress, redwood, and Western redcedar, which have a Nation-wide specialty market as siding and shingle woods.

12.3. REQUIREMENTS FOR SPECIFIC HOUSING USES.—It is not often that a single property controls the choice of wood for a given use in housing. Usually the controlling factor in the selection is the degree to which two or more properties are combined. For example, a wood that is high in stiffness may not be the most suitable species for a use where this property is important because it may be too low in bending strength; a wood of higher bending strength but still possessing good stiffness would likely be more suitable in house construction.

It is not always possible to select the "best" wood for a given use. As a rule, alternate woods can be used for the same purpose. Sometimes it is necessary to make adjustments in dimensions to utilize a lighter-weight wood where given requirements of strength are to be met. Again, a wood that has naturally low decay resistance can be treated with preservatives to fit it for the job; frequently such woods are found to take preservative treatment quite readily. In short, a species cannot be ruled out because it appears to be inferior in one respect or another. Only the more commonly used woods for specific parts of houses are listed in this chapter. The reader will find information concerning wood properties of many species in other chapters that will assist him in selecting additional species on the basis of the properties discussed in this chapter.

12.30. Framing Members.—Stiffness and bending strength are the primary mechanical properties needed for most structural members of houses, such as studs and joists. Other desirable properties include low shrinkage, good nail-holding power, and freedom from pronounced warp. Stiffness, which is a measure of deflection under load, is necessary to a high degree in joists and studding of conventional construction because it minimizes plaster cracks. This

property is also important in prefabricated nailed construction when a plaster finish is used. When some other covering such as fiberboard or plywood is used, the stiffness is of considerably less importance. Any deficiency in the stiffness of a species can, of course, be compensated for by increasing the size of the member. For example, a 10-inch joist has about one-fourth more wood than an 8-inch joist but it is more than twice as stiff.

The basic properties of the framing members for stressed-cover panels are somewhat different than for prefabricated nailed houses in that the ability of the framing members to take glue satisfactorily is highly important. In this respect, wane and other defects resulting in lack of square edges, and knots, make an unsatisfactory glue surface. Only relatively small knots should be permitted (sec. 14.30).

The woods more commonly used for framing members in prefabricated nailed houses and conventionally constructed houses include Douglas-fir, southern yellow pine, Eastern hemlock, Western hemlock, spruce, and white fir. For the framing members of panels with stressed coverings, species that are easily worked and are relatively free of warp are desirable. Such species would include Douglas-fir, the commercial white pines, spruce, Western hemlock, and redwood. Grading principles for framing lumber are discussed in section 4.0211.

12.31. Coverage.

12.310. Subfloors.—The requirements for subflooring are not exacting. It is desirable, however, that woods be selected that are high in stiffness, of medium shrinkage and warp, easy to work, and of adequate nail-holding power. Since stiffness is little affected by such defects as knots and checks, material containing these defects may be used satisfactorily because stiffness is usually more important than bending strength.

The lower grades of boards are ordinarily considered satisfactory for subfloors. The species commonly used include Douglas-fir, Western larch, southern yellow pine, the hemlocks, white fir, ponderosa pine, and spruce. Plywood is being used more extensively for subfloors and is a highly satisfactory material for this purpose. In houses with floor panels having stressed coverings, Douglas-fir plywood is commonly used. Where a finished wearing surface is combined with a panel covering, the outer ply of the top plywood covering is often of a hardwood species such as oak or birch. This covering is frequently prefinished in the factory.

12.311. Wall Sheathing.—All woods can be used for sheathing in prefabricated nailed construction with satisfactory results. The primary requirements are ease of working, ease of nailing, and moderate shrinkage. Some woods are, of course, less time consuming to apply than others. As in subfloors, defects such as knots and checks are not important. The woods commonly used for this purpose include the hemlocks, ponderosa pine, white fir, Douglas-fir, Western larch, and southern yellow pine. Woods that tend to split in nailing and that warp and twist and are relatively heavy usually cost more to apply than do the more easily handled woods, although when properly applied they will still give a good finished job. In prefabricated constructions employing stressed coverings, plywood is ordinarily used. The grade of plywood required is described in section 12.1.

12.312. Roof Boards.—High stiffness, good nail-holding power, small tendency to warp, and ease of working are the more important requirements for roof boards. Defects such as knots and checks are ordinarily permitted because they do not detract from stiffness, and bending strength is usually ample even for low-grade material. The woods commonly used for roof boards are Douglas-fir, Western larch, southern yellow pine, the hemlocks, ponderosa pine, spruce, and white fir. Basic grades of lumber suitable for roof boards are described in section 4.0211.

Plywood is frequently used for roof coverings in conventional, prefabricated nailed, and prefabricated glued constructions employing stressed-covered panels. For conventional and prefabricated nailed, the lower grades of waterproof plywood are especially well adapted. With housing using panels with stressed coverings the Sound-One-Side grade or its equivalent is ordinarily used.

12.313. Siding.—The usual requirements for siding are good painting characteristics, easy working qualities, and freedom from warp. There is considerable variation among woods as to their painting characteristics, particularly for outdoor exposure. In general, woods

of light weight hold paint better than heavier woods. Also, the species with narrow bands of summerwood hold paint better than woods such as Douglas-fir or southern yellow pine, which have relatively wide bands of summerwood. Edge-grain surfaces also hold paint better than flat-grain surfaces. This subject is more fully discussed in chapter 7. The woods commonly used for siding include the white pines, Western redcedar, baldcypress, and redwood. For low-cost construction where paint characteristics are not of first importance, Douglas-fir and southern yellow pine are often used.

12.314. Shingles.—The properties most essential for shingles include high decay resistance, small tendency to curl or check, and freedom from splitting during nailing. Various woods are classified as to decay resistance in section 3.81. Sapwood of all species is low in decay resistance and the better shingles are made entirely of the heartwood. Edge-grain shingles are superior to flat-grain shingles in that they have considerably less tendency to warp in service. The principal woods used for shingles are Western redcedar, Northern white-cedar, baldcypress, and redwood. All-heart, edge-grain, clear stock should be used for longest life and greatest ultimate economy in dwelling roofs.

12.315. Exterior Trim.—Woods used for exterior trim should combine medium decay resistance, good painting qualities and weathering characteristics, ease of working, and maximum freedom from warp. Woods having the required heartwood resistance to decay are listed in section 3.81.

The location of the trim has some bearing upon the required characteristics of the wood used. For example, blinds, rails, balcony and porch trim have a high decay hazard and heartwood only should be used. Where drainage is good or adequate protection is provided, as by overhanging eaves or other construction features, the necessity for high decay resistance is not so critical. Basic grades of exterior trim are given in section 4.011 and 4.02110. Woods commonly used for exterior trim of high-quality houses include Western redcedar, baldcypress, and redwood. The hemlocks, ponderosa pine, spruce, and white fir are sometimes used where the drainage is good. Douglas-fir, Western larch and -southern yellow pine are also used, but special priming treatment is advisable to improve the paint holding qualities.

12.316. Flooring.—The requirements for flooring woods vary somewhat with the nature of the service they are intended to perform. Woods for living-room and bedroom flooring require high resistance to wear, attractive figure or color, and minimum warping and shrinkage. Those for kitchen flooring also require high resistance to wear, but fine texture and ability to withstand washing and wear without discoloring are more important than attractive figure or color. Resistance to slivering, minimum warping, and shrinkage are also desirable qualities. Porch flooring should have good resistance to decay, medium wear resistance, nonsplintering, and freedom from warp.

Hardness is an indication of the wearing qualities of the wood. The harder the wood, other things being equal, the more resistant it is to wear, and the better it can be polished. On the other hand, the more difficult it is to cut and nail and the more likely it is to split in nailing. In some woods, such as southern yellow pine and Douglas-fir, there is a pronounced difference between the hardness of the springwood and summerwood. In such woods edge-grain flooring usually wears better because the springwood and summerwood bands are less pronounced, and the wood wears more evenly and is less likely to splinter than flat-grain material. In such woods as oak, the wide summerwood bands do not interfere greatly with uniformity of wear because the hardness of the summerwood and springwood are more nearly equal. In woods like maple, which do not have pronounced summerwood and springwood, the texture is relatively uniform and such woods wear very uniformly and give exceptionally good service. Woods commonly used for flooring in high-quality houses include hard maple, oak, beech, birch, and black walnut. For more economical flooring, Douglas-fir and southern yellow pine are extensively used. Both flat-grain and edge-grain are used, but edge-grain is preferable because it wears more uniformly and is less likely to splinter. For kitchen flooring that is uncovered, hardwood of uniform texture is ordinarily used, which includes such species as beech, birch, and hard maple. The woods for porch flooring ordinarily include baldcypress, Douglas-fir

(vertical grain), Western larch (vertical grain), southern yellow pine (vertical grain), redwood, and white oak. Basic grades for flooring lumber are given in sections 4.012 and 4.02110.

12.32. Millwork.

12.320. Interior Trim.—Interior trim comes in two grade classifications, interior trim for natural finish, or interior trim for paint finish. The usual requirements for interior trim to receive a natural finish include a pleasing figure, hardness, and freedom from warp. Woods commonly used for natural finish include birch, oak, and to a lesser extent such woods as ash, cherry, sycamore, and walnut.

Requirements for trim with a paint finish include fine and uniform texture, hardness, absence of discoloring pitch, freedom from warp and shrinkage. The softer species, such as Eastern white pine, ponderosa pine, sugar pine, and Western white pine, are commonly used.Where marring is likely to occur, and a wood that takes a good paint finish is required, birch and yellow-poplar are frequently used. Other woods often used include redwood, spruce, sweetgum, basswood, maple, Douglas-fir, and southern yellow pine. The principles upon which the grading of interior trim for natural and paint finishes are based are discussed in sections 4.011 and 4.02110.

12.321. Sash.—The use requirements of sash determine the properties necessary for good service. Sash used in a dry location need not have such high decay resistance as sash used in moist locations, but otherwise the requirements are the same. They include moderate shrinkage, good paint qualities, freedom from warping, ease of working, and screw-holding power. Woods commonly used for sash include the white pines, ponderosa pine because of its availability, baldcypress, and redwood. Douglas-fir, Western larch, and southern yellow pine are also used to some extent.

12.33. Girders, Piers, Posts.—The usual requirements for girders include good decay resistance and relatively high strength. Similar properties are desirable for such members as piers and posts. Sill plates should also be high in decay resistance, should hold nails satisfactorily and be resistant to crushing, although the bending strength is usually not of particular importance. Because of the size commonly required for girders, the choice is limited to the species where large sizes can be obtained and which are of good strength, such as Douglas-fir, Western larch, and southern yellow pine. A variety of species is often used for piers or posts, but those with high decay resistance are naturally to be preferred.

JOINTS AND FASTENINGS

13.0. GENERAL.—The strength and safety of any structure are dependent upon efficient joining together of its elements. No structure is stronger than the joints and fastenings that hold it together; as a rule, in fact, the weakest parts of the structure are its joints. This is true for structures made of wood no less than for those made of any other material.

Figure 13–1 shows a variety of woodworking joints. Some of these joints occur commonly with mechanical fastenings, others definitely require a fastening medium such as glue, while still others can be used with either mechanical fastenings or glue. The simple butt joint shown in figure 13–1, A, generally requires lap splices if mechanically fastened. Joints shown in figure 13–1, *D, E, K,* and *L* are commonly nailed, bolted, or screwed. On the other hand, such joints as *B, C, F, G, H, I,* and *J* of figure 13–1 are glued; fastening would be more or less difficult with nails, screws, or bolts. The adaptability of some of these joints to gluing—particularly the ones more complex to machine—is discussed in section 13.2.

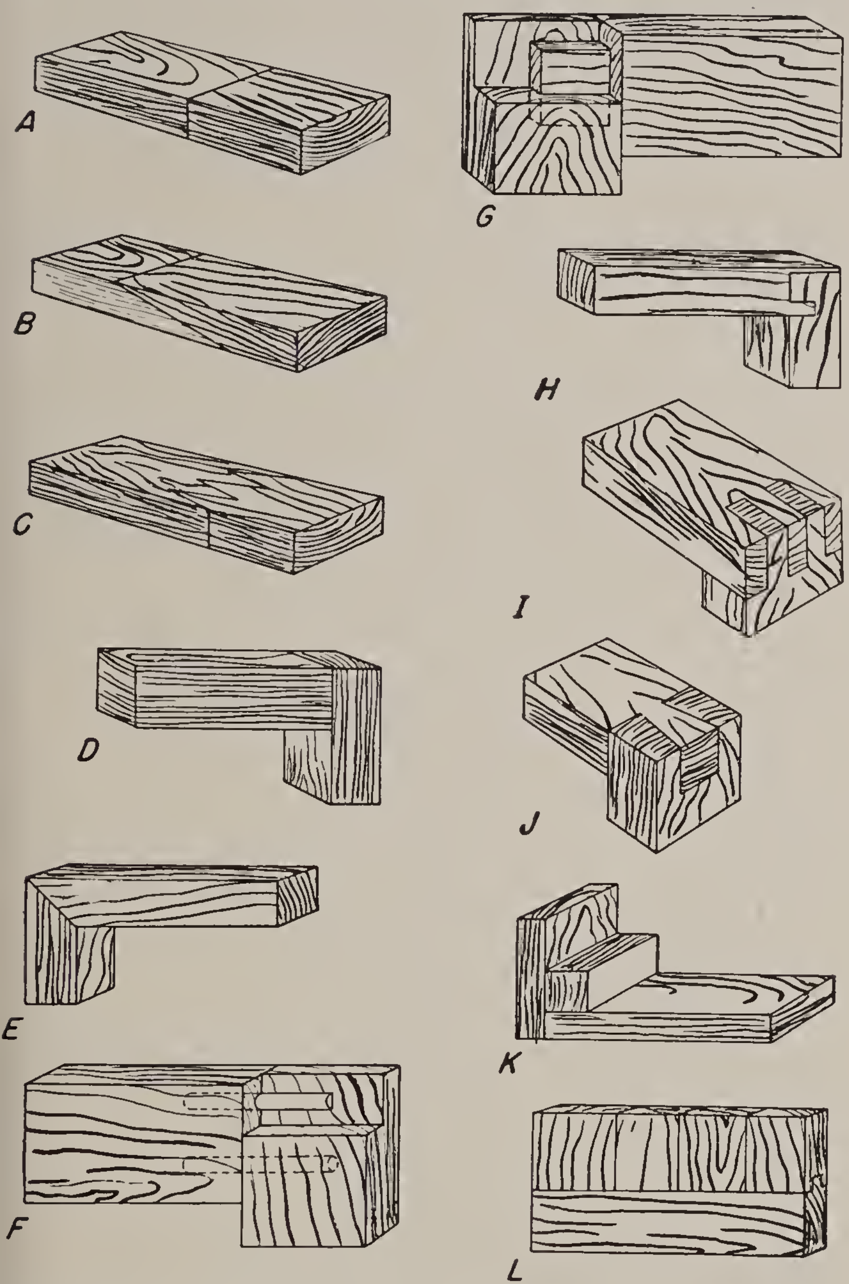

FIGURE 13–1.—Types of joint construction. *A*, butt; *B*, scarf; *C*, serrated or finger; *D*, end-grain to side-grain butt; *E*, miter; *F*, dowel; *G*, mortise and tenon; *H*, dado tongue and groove; *I*, slip or lock-corner; *J*, dovetail; *K*, blocked; *L*, tongued and grooved joint.

The art of joining materials has always exercised the ingenuity of man. In no field has the development been carried, from the standpoint of intricacy of design, farther than in woodworking. In general, however, the simpler joints, such as the butt, scarf, and blocked joint, have retained their popularity. The reasons for their continued use are not far to seek. The mating parts can be easily and quickly shaped to close tolerances, and the joined parts can be held together with a variety of fastenings. Moreover, in a material such as wood, which is subject to dimensional changes, the effects of the changes are more susceptible to control in a simple than in a complex joint.

The factors that govern good joint construction can be summed up as follows:

1. The joint must provide an adequate "bridge" for the transfer of loads from one member to the other.

2. Where glue is the fastening medium, the joint must not be unduly affected by the natural swelling or shrinking of the members. In wood, such dimensional changes may differ substantially in amount between joined members exposed to widely fluctuating moisture conditions.

3. The mating surfaces must be simple, to facilitate accurate machining and joining.

4. The joint must be so designed that, where mechanical fastenings are used, adequate edge, end, and depth clearances are allowed, and

where glue is used, adequate gluing area is provided.

5. The design of the joint should permit effective sealing against infiltration of wind, rain, dirt, and similar hazards.

6. With a nonhomogeneous material such as wood, the joint should be designed to mate the parts most effectively with respect to direction of grain, strength properties, and other factors.

There are no hard and fast rules that dictate the type of fastening that must be used in a given joint. Size of the joined members, loads that will be carried, simplicity of design and fabrication, and economy all play a part. It is the responsibility of the designer to select what is in his judgment the most suitable fastening for a particular joint. In general, he will strive for the strongest joint possible within the limitations of a given joining problem.

13.1. MECHANICAL FASTENINGS.

13.10. General.—In conventional construction, mechanical fastenings, principally nails, furnish the usual means of joining the structural members. Other mechanical fastenings are used to only a limited extent. In prefabricated construction glue joints play a more important part, especially in stressed-cover construction. Mechanical fastenings are, however, of importance, particularly for joining panels and sections in final assembly. Bolts and lag screws find considerable use in such connections. Modern connectors may find use for joining members of light roof trusses (sec. 14.12).

The size, number, and arrangement of fastenings in conventional construction have been determined largely by experience, precedent, and judgment of the individual carpenter. Prefabricated construction, with its opportunities for new and better methods of construction, offers also the opportunity of more scientific use of materials and the design of structures. Such design involves a knowledge of the strength of the various mechanical fastenings. Succeeding sections give fundamental data on the strength of various fastenings, and related information for use in design.

13.11. Nails and Spikes.

13.110. General.—Nails and spikes find considerable use in conventional house construction; depending upon the type of prefabrication system used, they may find considerable use in prefabricated houses.

Common wire spikes are manufactured in the same manner as common wire nails. They have either a chisel point or a diamond point and are made in lengths of 3 to 12 inches. For corresponding lengths they have larger diameters than common wire nails and beyond the sixtypenny size are usually designated by inches of length.

13.111. Direct Withdrawal.—The holding power of nails and spikes is dependent primarily on the pressure and consequent friction between the wood and the nail. Nails driven into the side grain of wood cut, break, and compress the wood fibers and bend them downward. The compressed and bent fibers press upon the nail surface and furnish the pressure that resists withdrawal. Immediately after driving, that pressure is great. When drying takes place, however, the fibers shrink and the end-grain fibers, which were bent downward, may lose their contact, while side pressure may increase because shrinkage has changed the shape of the hole from round to oval. Nails have greater holding power in side grain than in end grain and nailing into end grain is, therefore, poor practice.

The resistance of nails and spikes to withdrawal is influenced by the species of wood, the surface condition of the nail shank, the form of the shank, the diameter of the shank, and the character of the nail point. The greater the specific gravity (density) of the wood, the greater is its holding power. The dense, heavy woods thus have much greater holding power than the light-weight woods.

The surface condition of the shank is an important factor in determining the holding power of nails and spikes. Eight types of surface conditions are shown in figure 13–2. The smooth nail is most commonly used in house construction. A number of attempts have been made to improve the holding power of nails, some of which, such as the annular-grooved, spirally grooved, and barbed, are shown in figure 13–2. While these types of shanks have certain advantages, principally in the retention of holding power with changes in moisture content, they have certain disadvantages, and their net advantages have not been sufficient to overcome the advantages of the round shank in simplicity and cost of manufacture, ease of driving, and equal stiffness in all direc-

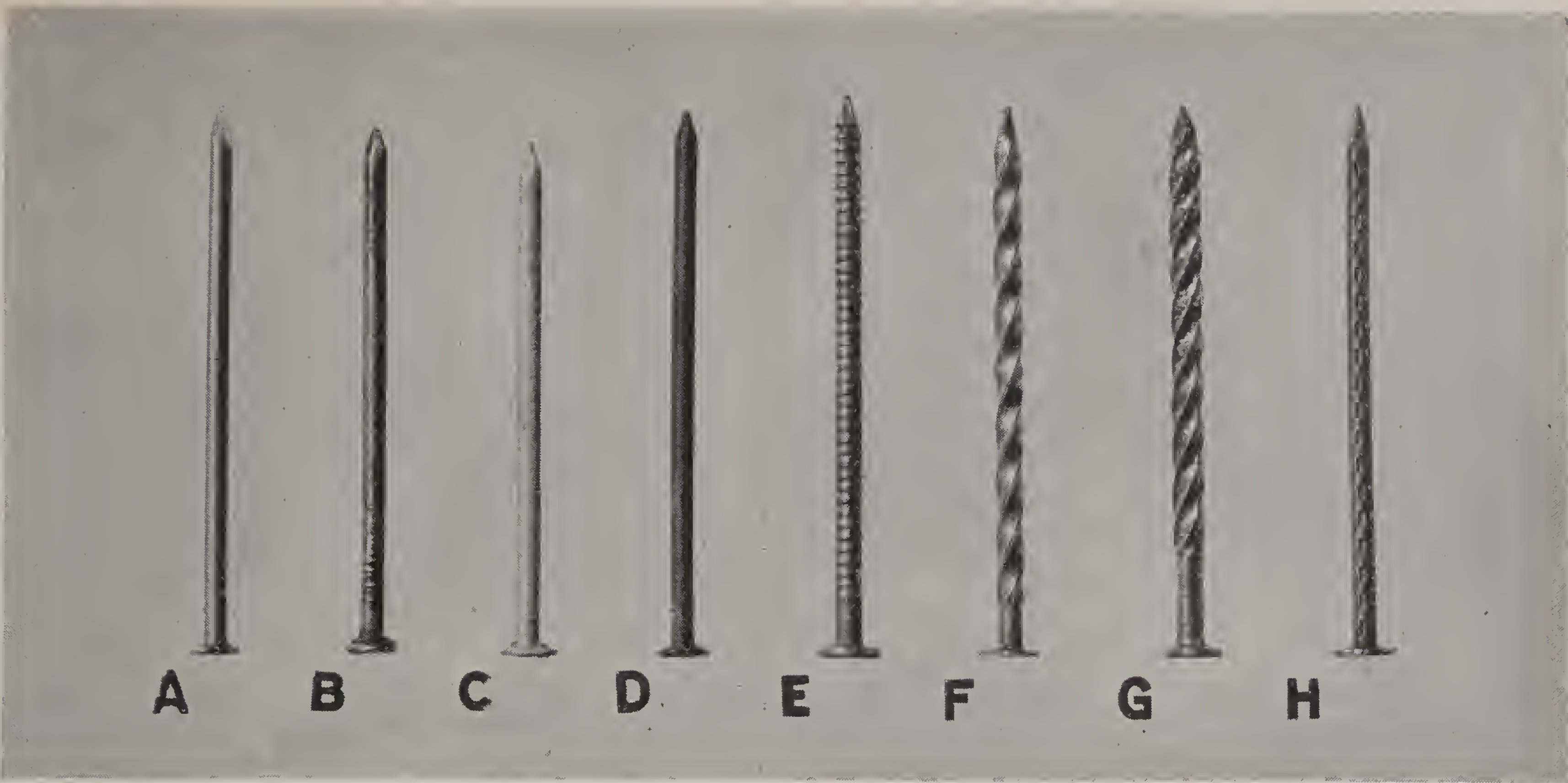

FIGURE 13–2.—Eight types of surface conditions used with nails: *A*, smooth nail; *B*, cement-coated; *C*, zinc-coated; *D*, chemically-etched; *E*, annular-grooved; *F*, smooth spirally grooved; *G* rough spirally grooved; *H*, barbed.

tions. Preliminary data, however, indicate that the annular-grooved nail may offer considerable advantage in high initial holding power, retention of holding power, and ease of driving.

The points of nails or spikes (fig. 13–3) affect both the amount of splitting that occurs in driving them and their holding power. Their influence on splitting is more important than their influence on holding power. Contrary to general belief, the blunt-pointed nail has less tendency to split wood in driving than does the sharp-pointed nail. The blunt point tears the wood fibers, whereas the sharp point produces a wedging action that causes splitting (fig. 13–4). The sharp-pointed nail, however, has a greater holding power provided it does not split the wood. The truncated point shown in figure 13–3, *D*, was developed to reduce the

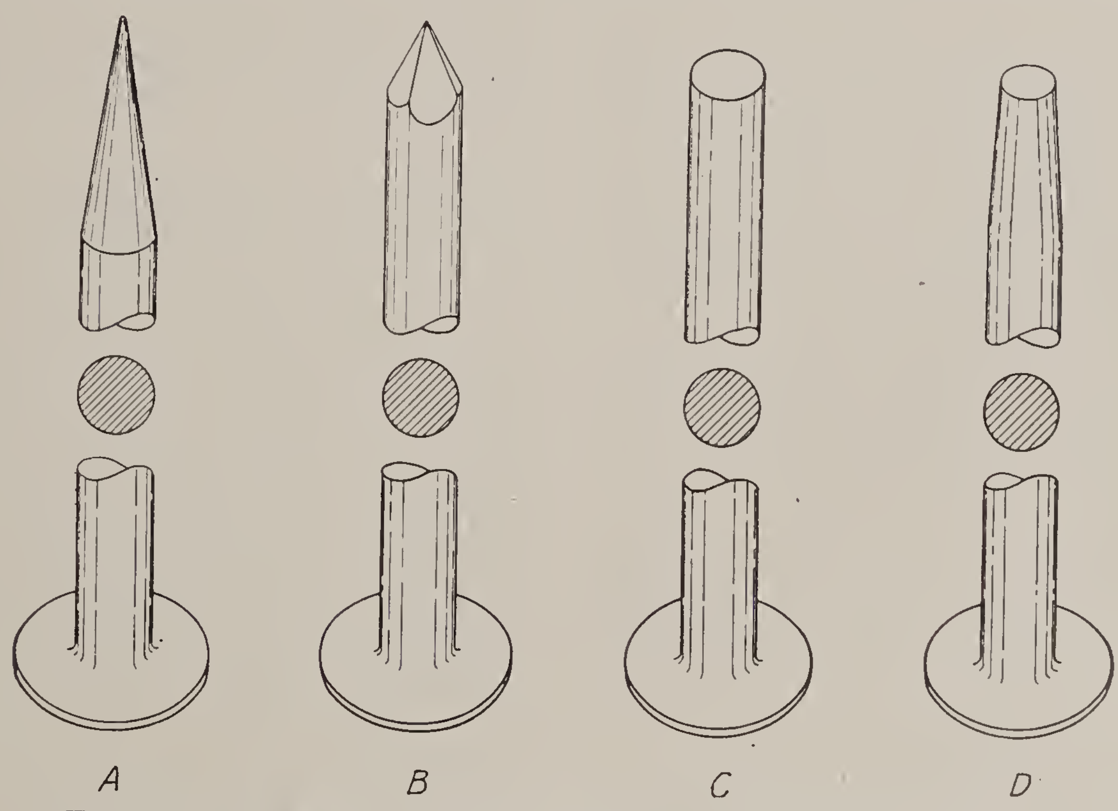

FIGURE 13–3.—Types of nails points: *A*, sharp; *B*, common; *C*, blunt; *D*, truncated.

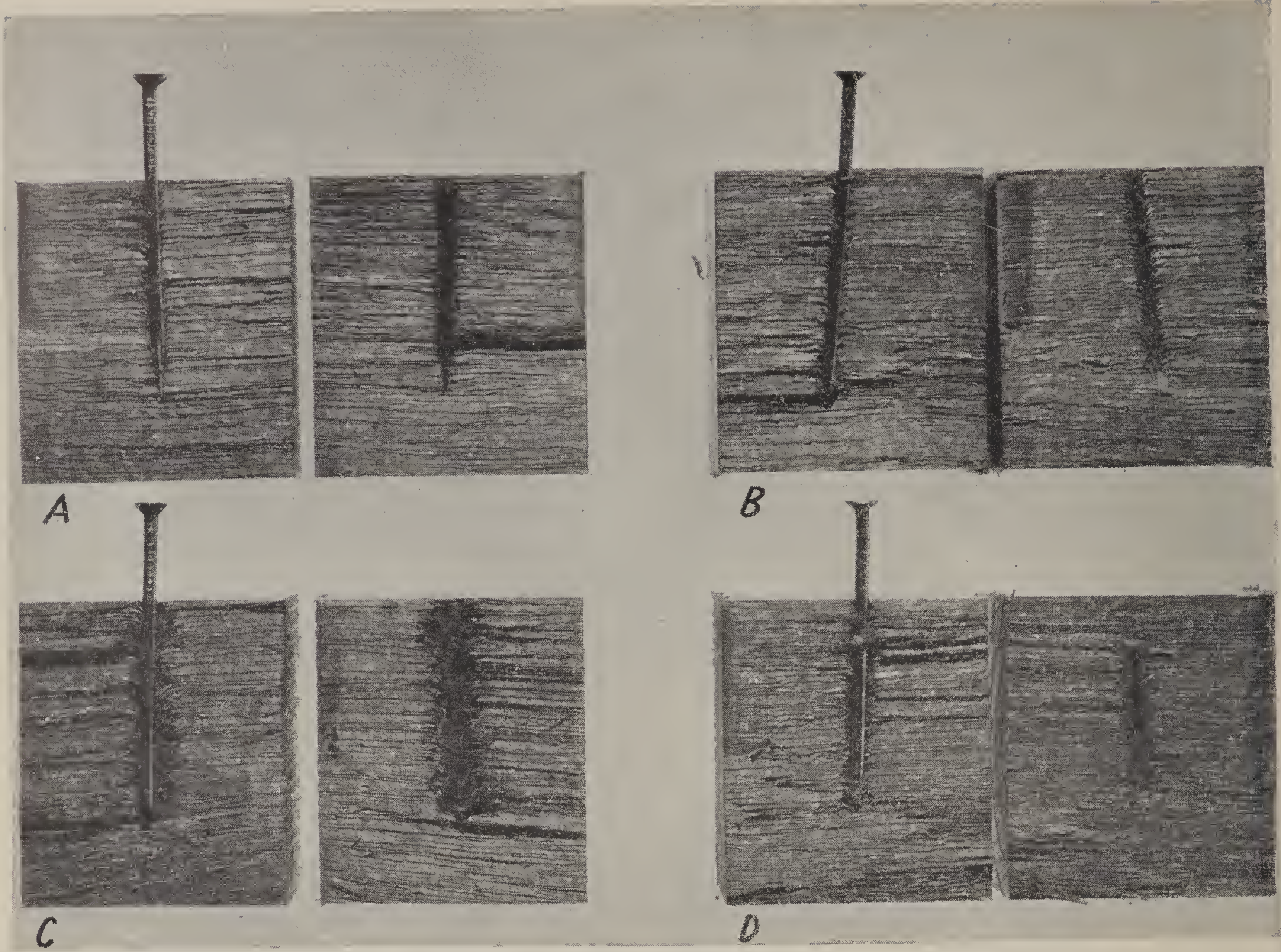

FIGURE 13–4.—Character of fiber distortion caused by nails with four different types of points in blocks subsequently split: A, sharp; B, common; C, blunt; D, truncated.

splitting caused by a full sharp point while still retaining the holding power. It is fully the equal of the common point (fig. 13–3, B) in holding power but has much less tendency to split the wood. The effect of points on both holding power and splitting is eliminated by driving the nails into prebored lead holes. Further, the boring of lead holes reduces the loss of holding power that occurs with changing moisture conditions, due to the fact that there is less distortion of the wood fibers.

Tests made at the Forest Products Laboratory indicate that the load required to withdraw common wire nails or spikes soon after driving into the side grain of seasoned wood is given by the formula:

$$P = 6{,}900\ G^{5/2} D$$

Where P is the ultimate load per lineal inch of penetration, G is the specific gravity of the wood based on oven-dry weight and volume when oven-dry, and D is the diameter of the nail in inches.

If a factor of 6 is applied to this equation, the safe load (P_1) becomes

$$P_1 = 1{,}150\ G^{5/2} D$$

The relationships expressed in these equations are general, and certain species are known to give somewhat higher values whereas others fall below the equation values. The general equations should therefore be used with reservation. Usually, common knowledge of the characteristics of a species with particular reference to its splitting tendencies will aid in deciding whether it will fall above or below the general run of species. Values of G for various species can be obtained from table 5–1.

In table 13–1 are given safe withdrawal loads for a number of species and nail sizes

TABLE 13-1.—*Safe resistance to direct withdrawal of common wire nails driven perpendicular to the grain into seasoned wood. (Values in pounds per inch of penetration into the main member receiving the point)*

Species	Specific gravity [1]	Size of nail									
		6 d	8 d	10 d	12 d	16 d	20 d	30 d	40 d	50 d	60 d
Birch, sweet and yellow	0.69	51	60	67	67	74	87	94	102	111	120
Douglas-fir	.51	24	28	32	32	35	41	44	48	52	56
Maple, sugar	.68	50	57	65	65	71	84	91	99	107	115
Oak, red and white	.69	51	60	67	67	74	87	94	102	111	120
Pine, Eastern white	.37	13	15	17	17	19	22	24	26	28	30
Pine, longleaf	.64	34	39	45	45	47	50	55	59	64	69
Pine, ponderosa	.42	15	17	19	19	21	25	27	30	32	35
Pine, shortleaf	.59	28	32	36	36	38	41	44	48	52	57
Redwood	.42	15	17	19	19	21	25	27	30	32	35
Spruce, Sitka	.40	14	17	19	19	21	25	27	29	31	34

[1] Based on weight and volume when oven-dry.

calculated by the foregoing formula, except that adjustments have been made for a few species to bring them into close agreement with test values.

Nails driven into the green wood of most species will lose a large part of their holding power, some more and some less, when seasoning occurs. Aside from the fact that nail-holding power becomes erratic under such conditions, it is difficult to predict how an individual species will behave.

13.112. Lateral Resistance.—In many applications in housing, as in the resistance of sheathing to racking loads, the lateral resistance of nails is of more importance than the resistance to direct withdrawal.

Tests at the Forest Products Laboratory have resulted in the recommendation of safe loads of wire nails and spikes as calculated by the formula:

$$P = KD^{3/2}$$

Where P is the safe lateral load in pounds, K is a constant depending on the species, and D is the diameter of the nail in inches.

The actual equations for various species are shown in table 13-2. In general, they were obtained by dividing the factors in the general equations for proportional limit loads (from tests) by an arbitrary factor of 1.6. Strictly, they apply to wood at a moisture content of about 15 percent. Maximum loads for coniferous species will be about 6 times and for hardwoods about 11 times the recommended safe values.

For convenience in using the equations of table 13-2, table 13-3 gives values of $D^{3/2}$, corresponding to various sizes of common wire nails and common wire spikes.

The recommendations are based on penetration into the block receiving the point of not less than 10 times the diameter of the nail or spike for dense hardwoods to 14 times the diameter of the nail or spike for the softwoods. They also assume that the cleats are not greatly different in density from the blocks receiving the points. If the nails are holding metal to wood, the safe lateral loads may be increased by 25 percent.

13.12. Screws.

13.120. Wood Screws.—Wood screws find their principal use in housing in the attachment of hardware such as door latches, window han-

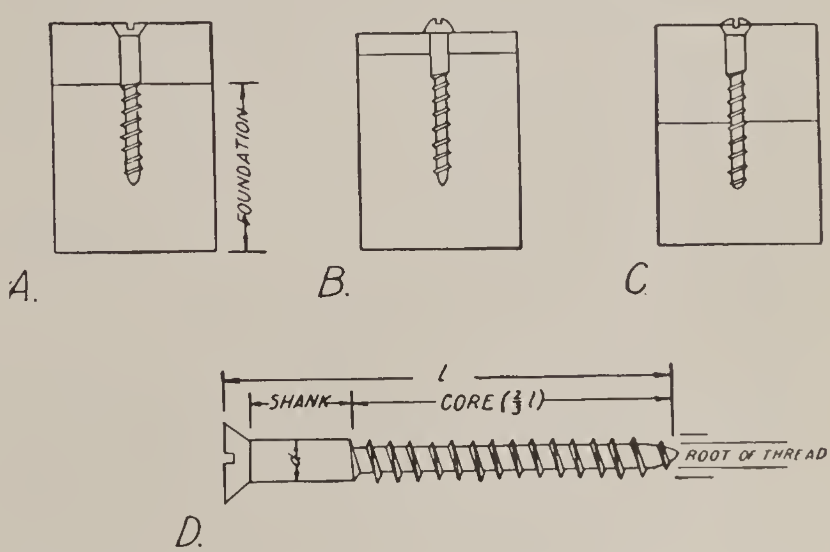

FIGURE 13-5.—Types and principal parts of wood screws: *A*, flat head; *B*, round head; *C*, oval head; *D*, parts and dimensions, where *l* represents the length and *d* the shank diameter. Screws inserted as in *A* have maximum resistance to direct withdrawal; as shown in *B*, maximum lateral resistance; while those inserted as in *C* have relatively low resistance in both properties.

Table 13–2.—*Equations for computing safe lateral resistance for common wire nails driven perpendicular to the grain of wood at 15 percent moisture content expressed in pounds per nail*

Species of wood	Equation
HARDWOODS	
Aspen, quaking and bigtooth	
Basswood, American	
Chestnut, American	$P = 900\ D^{3/2}$
Cottonwood, black and Eastern	
Yellow-poplar	
Ash, black	
Birch, paper	
Cucumbertree	
Elm, American and slippery	
Hackberry	
Magnolia, Southern	$P = 1{,}250\ D^{3/2}$
Maple, bigleaf	
Maple, soft (red and silver)	
Sweetgum	
Sycamore	
Tupelo, black and water	
Ash, commercial white	
Ash, Oregon	
Beech, American	
Birch, sweet and yellow	
Elm, rock	$P = 1{,}700\ D^{3/2}$
Hickory, true and pecan	
Maple, hard (black and sugar)	
Oak, commercial red and white	
Walnut, black	
SOFTWOODS	
Fir, balsam and commercial white	
Hemlock, Eastern	
Pine, lodgepole, ponderosa, sugar, Eastern white, and Western white	$P = 900\ D^{3/2}$
Spruce, Engelman, red, Sitka, and white	
White-cedar, Atlantic and Northern	
Baldcypress	
Douglas-fir (Rocky Mountain Region)	
Hemlock, Western	
Incense-cedar, California	
Pine, red	$P = 1{,}125\ D^{3/2}$
Redcedar, Eastern and Western	
Redwood	
Tamarack	
White-cedar, Port Orford	
Yellow-cedar, Alaska	
Douglas-fir (Coast Region)	
Larch, Western	$P = 1{,}375\ D^{3/}$
Pine, southern yellow	

dles, and butts. While holding power, either lateral or direct, is of importance in these uses, screw sizes are generally standardized and the screws are generally furnished with the hardware. Wood screws may occasionally, however, be used to furnish gluing pressure in glued assemblies or to supplement the strength of the glued joint as a matter of safety in case the glue should deteriorate.

The common types of wood screws have flat, oval, or round heads. The flat-head screw is the type most commonly used where a flush surface is desired. Oval-head and round-head screws are used for appearance or when countersinking is objectionable. Besides the head, the principal parts of a screw are the shank, thread, and core (fig. 13–5).

The withdrawal resistance of screws is dependent upon the specific gravity (density) of the wood holding the point, the diameter of the screw, the length of the screw, and the character of the screw thread and hole surface. It has also been found that screws having a rough thread surface appear to have greater resistance to withdrawal than those that are highly polished.

Table 13–3.—*Relation between size of nail expressed in pennies and $D^{3/2}$ applicable only to common wire nails and spikes for use in the equations of table 13—2*

Common wire nails		Common wire spikes	
Size	$D^{3/2}$	Size	$D^{3/2}$
Penny		*Penny*	
4	0.0311	10	0.0841
6	.0380	12	.0841
8	.0474	16	.0942
10	.0570	20	.1068
12	.0570	30	.1205
16	.0652	40	.1349
20	.0841	50	.1505
30	.0942	60	.1505
40	.1068	*Inch*	
50	.1205	7	.1747
60	.1349	8	.2296
		9	.2296
		10	.2296
		12	.2296

The resistance to withdrawal of screws 3 inches or less in length increases with diameter up to a certain limit; beyond that, an increase in diameter results in a decrease in withdrawal resistance. The optimum diameter increases with the length, and is smaller for dense woods than for lighter ones. The larger diameters of standard screws 3 inches or less in length, therefore, should be used only where considerations other than withdrawal resistance govern their selection.

Tests indicate that withdrawal resistance increases with length up to the point where the screw fails. This length decreases with density, so that the longer lengths should be avoided in the denser species.

The safe load per inch of length of screw in resistance to withdrawal from the side grain

TABLE 13–4.—*Equations for computing safe lateral loads for wood screws driven perpendicular to the grain of wood at 15 percent moisture content expressed in pounds per screw*

Species of wood	Equation
HARDWOODS	
Aspen, quaking and bigtooth; Basswood, American; Chestnut, American; Cottonwood, black and Eastern; Yellow-poplar	$P = 2{,}100\ D^2$
Ash, black; Birch, paper; Cucumbertree; Elm, American and slippery; Hackberry; Magnolia, Southern; Maple, bigleaf; Maple, soft (red and silver); Sweetgum; Sycamore; Tupelo, black and water	$P = 2{,}900\ D^2$
Ash, commercial white; Ash, Oregon; Beech, American; Birch, sweet and yellow; Elm, rock; Hickory, true and pecan; Maple, hard (black and sugar); Oak, commercial red and white; Walnut, black	$P = 4{,}000\ D^2$
SOFTWOODS	
Fir, balsam and commercial white; Hemlock, Eastern; Pine, lodgepole, ponderosa, sugar, Eastern white, and Western white; White-cedar, Atlantic and Northern	$P = 2{,}100\ D^2$
Baldcypress; Douglas-fir (Rocky Mountain Region); Hemlock, Western; Incense-cedar, California; Pine, red; Redcedar, Eastern and Western; Redwood; Tamarack; White-cedar, Port Orford; Yellow-cedar, Alaska	$P = 2{,}700\ D^2$
Douglas-fir (Coast Region); Larch, Western; Pine, southern yellow	$P = 3{,}300\ D^2$

of seasoned wood may be calculated from the formula:

$$P = 1{,}700\ GD^2$$

Where P is the safe load in pounds per inch of total length, G is the specific gravity based on oven-dry weight and volume at test, and D is the shank diameter of the screw in inches.

The formula is applicable to screws from ½ to 3 inches in length, provided the depth of penetration into the piece receiving the point is not less than two-thirds the length of the screw. For lengths outside the given range, loads will be somewhat lower, especially in denser species, where screw breakage may occur. The formula is based on a reduction from ultimate loads by a factor of 6. Safe loads for screws driven into end grain should be taken as about 75 percent of those for screws driven into side grain. Values for G may be taken from table 5–1.

Wood screws are generally driven into lead holes to reduce their tendency to split the wood. Greatest holding power will be obtained if two sizes of lead hole are used, one with the diameter and length of the shank and the other with a diameter of 70 percent for softwoods and 90 percent for hardwoods of the root diameter of the threads.

Maximum resistance to withdrawal is obtained when the shank penetrates the attached piece entirely, but does not penetrate the foundation member.

The lateral resistance of screws is of importance in some uses. Safe lateral loads may be calculated from the formula:

$$P = KD^2$$

Where P is the safe lateral load in pounds, K is a constant varying with species, and D is the diameter of the shank in inches. Values of K are given in table 13–4. The equation is valid for screws driven into wood at about 15 percent moisture content with a penetration into the foundation block of not less than 7 times the shank diameter. If metal is fastened to wood, the safe loads determined from the equation may be increased by 25 percent.

For convenience in using the equations of table 13–4, values of D^2 corresponding to various screw gages are as follows:

Shank diameter of screw *Gage*	D^2	Shank diameter of screw *Gage*	D^2
0	0.0036	9	0.0313
1	.0053	10	.0361
2	.0074	11	.0412
3	.0098	12	.0467
4	.0125	14	.0586
5	.0156	16	.0718
6	.0190	18	.0864
7	.0228	20	.1024
8	.0269	24	.1384

Screws should never be driven or started with a hammer, since their holding power is seriously reduced. Driving screws into end grain not only results in reduced holding power as compared with side grain, but increases the danger of splitting.

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TABLE 13–5.—*Equations for computing safe lateral resistance of lag screws driven perpendicular to the grain of wood at 15 percent moisture content and loaded parallel to grain, expressed in pounds per screw*

Species of wood	Equation
Fir, balsam and commercial white; Hemlock, Eastern; Pine, ponderosa, sugar, Eastern white, and Western white; Spruce, Engelmann, red, Sitka, and white; White-cedar, Atlantic and Northern	$P = 1{,}500\ D^2$
Aspen, quaking and bigtooth; Baldcypress; Basswood, American; Chestnut, American; Cottonwood, black and Eastern; Douglas-fir (Rocky Mountain Region); Hemlock, Western; Pine, red; Redcedar, Western; Redwood; Tamarack; White-cedar, Port Orford; Yellow-cedar, Alaska; Yellow-poplar	$P = 1{,}700\ D^2$
Ash, black; Birch, paper; Douglas-fir (Coast Region); Elm, American and slippery; Larch, Western; Maple, soft (red and silver); Pine, southern yellow; Sweetgum; Sycamore; Tupelo, black and water	$P = 1{,}900\ D^2$
Ash, commercial white; Beech, American; Birch, sweet and yellow; Elm, rock; Hickory, true and pecan; Maple, hard (black and sugar); Oak, commercial red and white	$P = 2{,}200\ D^2$

13.121. Lag Screws.—Lag screws may find use in prefabricated houses for anchorage or in joining panels. Their resistance to direct withdrawal and to lateral loads is of importance for such uses.

Resistance to direct withdrawal may be computed from the formula:

$$P = KD^{3/4}G^{3/2}$$

Where P is the ultimate withdrawal load in pounds per inch of penetration, K is a constant (7,500), D is the shank diameter in inches, and G is the specific gravity of the wood based on weight and volume when oven-dry. Figure 13–6 represents graphical solutions of this equation for various sizes of lag screws. Safe loads may be found by dividing the ultimate loads of figure 13–6 by 5.

The proper size of lead hole is important. Figure 13–7, *A*, shows the smooth, compact surface and deep thread penetration made by lag screws driven into lead holes of proper size, while *B* of figure 13–7 shows the rough surface and shallow thread penetration resulting when a lag screw is driven into a lead hole that is too large. For lightweight softwoods, such as the cedars and white pines, the lead hole should be 40 to 70 percent of the shank diameter; for Douglas-fir and southern yellow pine 60 to 75 percent; and for dense hardwoods, such as the oaks, 65 to 85 percent. In each case, the smaller percentages apply to screws of the smaller diameters and the larger percentages to screws of larger diameters.

Safe lateral loads for lag screws driven perpendicular and loaded parallel to the grain may be computed from the formula:

$$P = KD^2$$

Where P is the safe lateral load parallel to grain (pounds), K is a constant depending on species, and D is the shank diameter of the lag screw (inches). Values of K for various species may be found in table 13–5. The values obtained by use of the formula apply when the thickness of the attached member is 3.5 times the shank diameter. For other thicknesses, the allowable loads should be multiplied by the following factors:

Ratio of thickness of attached member to shank diameter	*Factor by which to multiply computed safe lateral loads*
2.0	0.62
2.5	.77
3.0	.93
3.5	1.00
4.0	1.07
4.5	1.13
5.0	1.18
5.5	1.21
6.0	1.22

Tests on lag screws under lateral load applied perpendicular to grain or at angles other than parallel have not been made. Other data, however, indicate that safe lateral loads perpendicular to grain may be computed by multiplying parallel-to-grain values by the following factors:

Shank diameter of lag screw *Inch*	*Factor*
3/16	1.00
1/4	.97
5/16	.85
3/8	.76
7/16	.70
1/2	.65
5/8	.60
3/4	.55
7/8	.52
1	.50

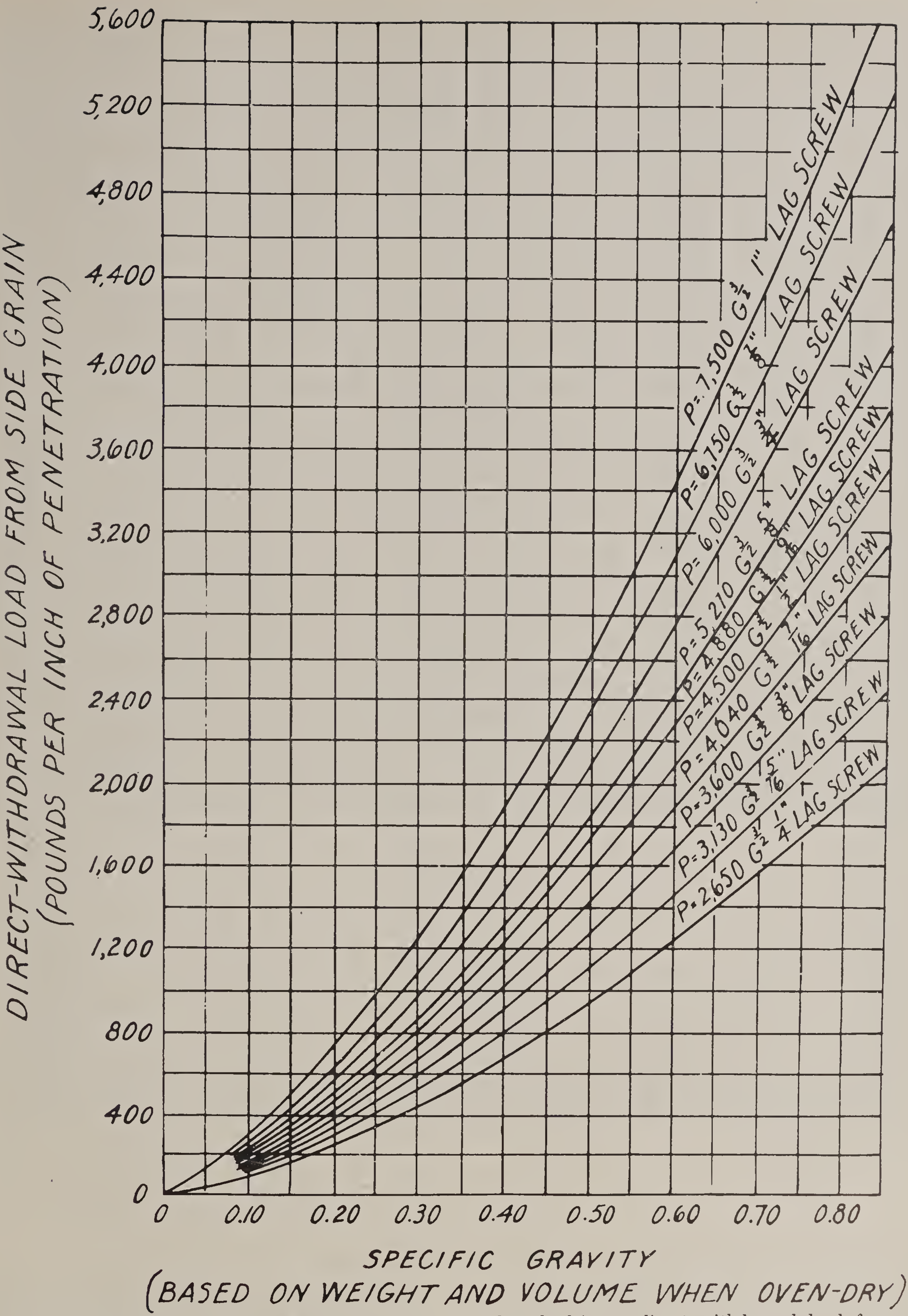

FIGURE 13–6.—Relation between specific gravity of wood and ultimate direct withdrawal load from side grain for lag screws ¼ to 1 inch in diameter.

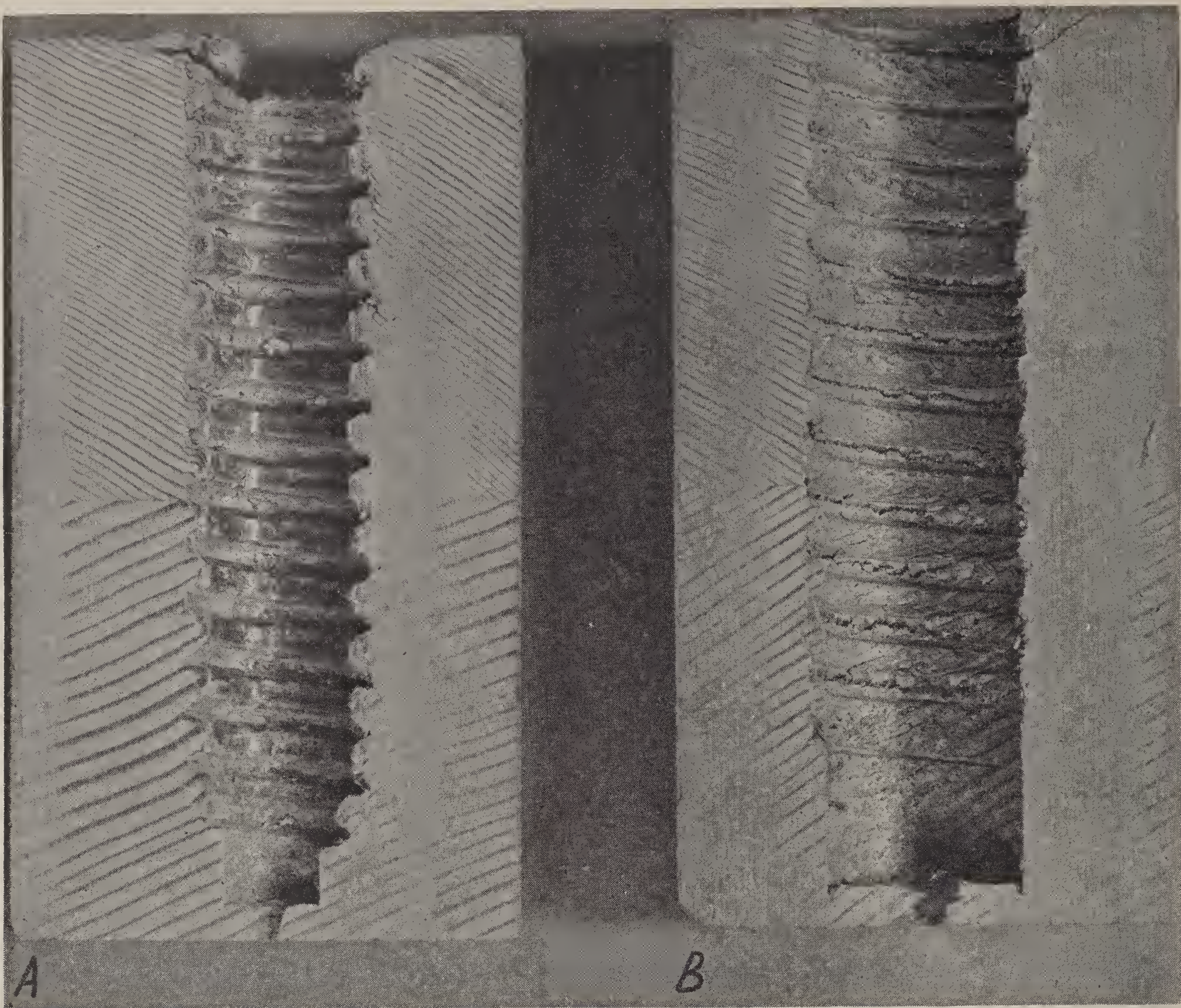

FIGURE 13–7.—*A*, clean-cut, deep penetration of thread made by lag screw driven into lead hole of proper size; *B*, rough, shallow penetration of thread caused by oversize lead hole.

For other angles, safe loads may be obtained by straight-line interpolation between parallel and perpendicular values.

Working values as computed above are based on the shank completely penetrating the attached piece but not penetrating the foundation piece. If the shank does penetrate the foundation piece, some increase in safe loads is permitted as follows:

Penetration of shank into foundation piece divided by shank diameter	Allowable increase in safe lateral loads
Inches	*Percent*
1	8
2	17
3	26
8	40

When lag screws are used with metal plates, safe lateral loads parallel to grain may be increased 25 percent, but no increase should be made in safe loads perpendicular to grain.

Lag screws should preferably not be driven into end grain. Withdrawal loads are only about three-fourths those for side grain and the danger of splitting, especially under lateral loads, is high.

Lag screws should never be driven or started with a hammer, since withdrawal loads are considerably reduced by this procedure. They should be turned in with a wrench, and it is desirable to use a lubricant such as soap or wax to facilitate driving, especially into dense species. Such lubricants do not affect holding power.

13.13. Bolts.

13.130. General.—Bolts are used in prefabricated house construction for joining panels and sections and at joints in light roof trusses.

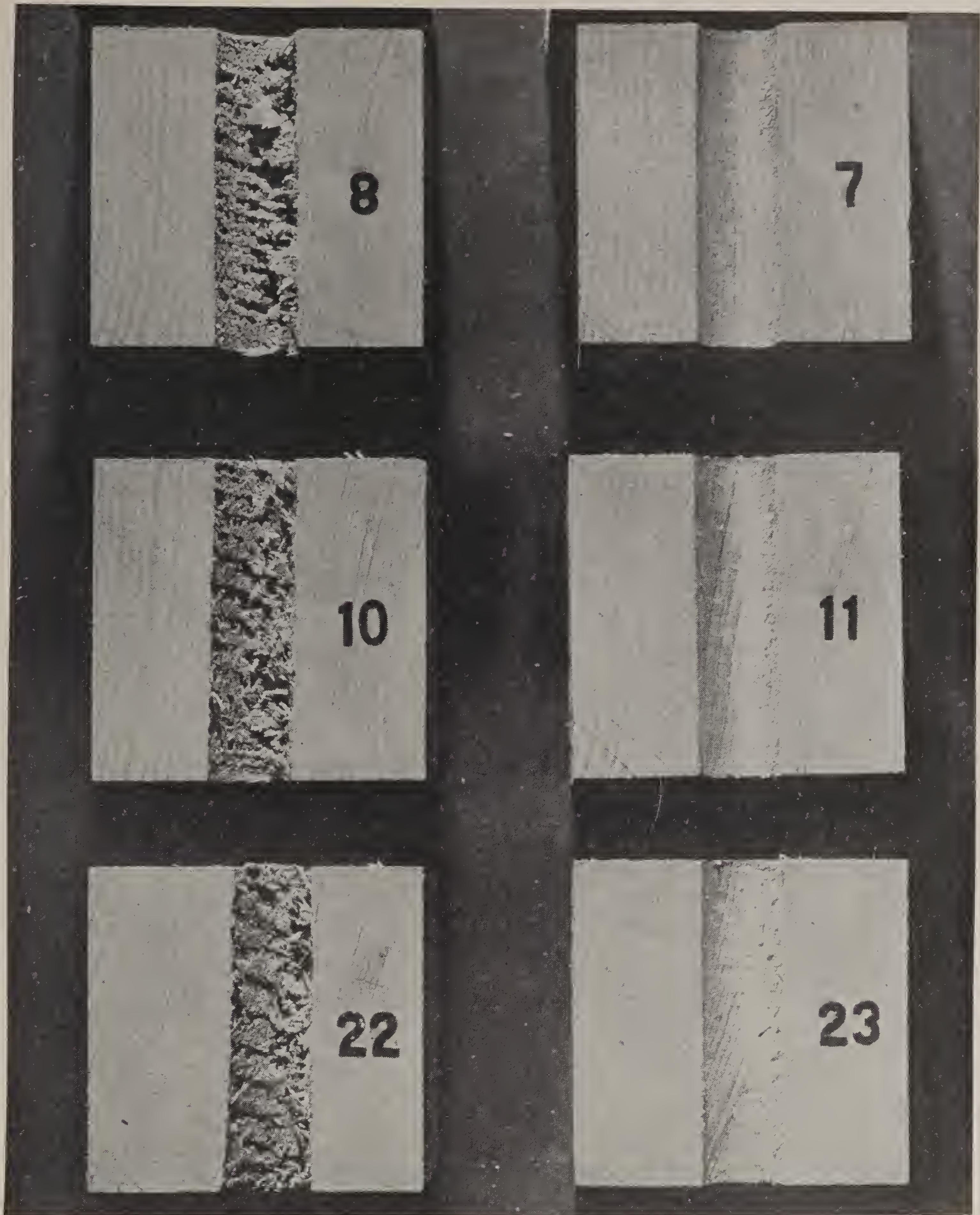

FIGURE 13–8.—Effect of rate of feed and drill speed on smoothness of holes drilled in softwood. Specimens 8, 10, and 22 were made with a twist drill at a speed of 200 revolutions per minute and a feed of 60 inches per minute; specimens 7, 11, and 23 were made with a twist drill operating at 800 revolutions per minute and a feed of 2 inches per minute.

Data on the bearing strength of wood under common bolts are furnished in this section. High-strength bolts, such as are used in aircraft, are available and carry higher loads than do common bolts, but their use in house construction would probably not be justified.

The bearing strength of wood under bolts depends largely upon the character of the holes

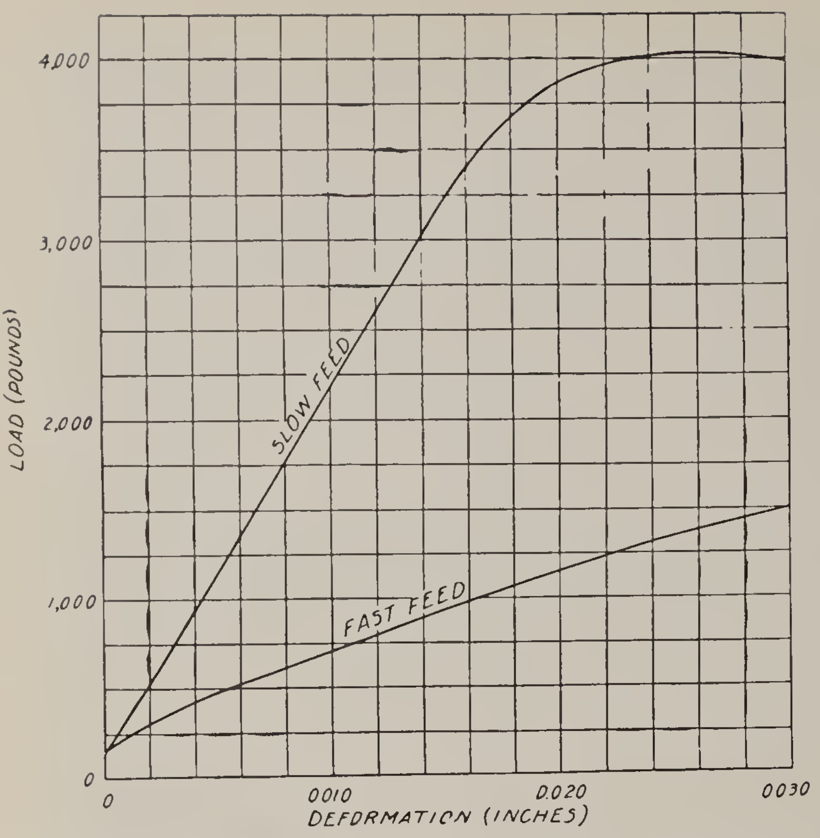

FIGURE 13–9.—Composite load-deformation curves showing the effects of surface characteristics of holes illustrated in figure 13–8 when subjected to bolt-bearing tests.

into which they are driven *(13–1)*. The surfaces of rough, carelessly-bored holes consist of a series of circular ridges (fig. 13–8). The valleys provide no bearing area, hence the bearing capacity is greatly reduced and excessive deformations are likely to result when the bolts are loaded (fig. 13–9). The surface of a properly bored hole is free from irregularities and usually has a distinct shine (fig. 13–8).

Rough holes result from the use of dull bits and from too rapid feeding (sec. 10.13). A twist drill, preferably machine-sharpened, produces smooth holes. The all-purpose drill having a 118° included angle gives satisfactory results. Manufacturers recommend peripheral speeds of 300 to 400 feet per minute for twist drills of high-speed steel when used in wood. The corresponding speed of rotation (in r.p.m.) can be computed approximately by dividing 1,350 by the diameter of the drill in inches. For carbon-steel drills, the speed of rotation should be approximately one-half that used for high-speed drills. The proper rate of feed depends upon the diameter of the drill and the speed of rotation, but should be such as to produce only thin shavings. The wood should be clamped, wedged, or otherwise held to prevent movement.

Bolts, to give high bearing values at low deformations, should fit the holes into which they are driven. A loose fit causes the bolt to bear only on a line. If the bolt hole is too small, the wood will split when the bolt is driven and the joint will have little strength. Normally, bolts should fit neatly so that they can be inserted by light tapping with a wood mallet.

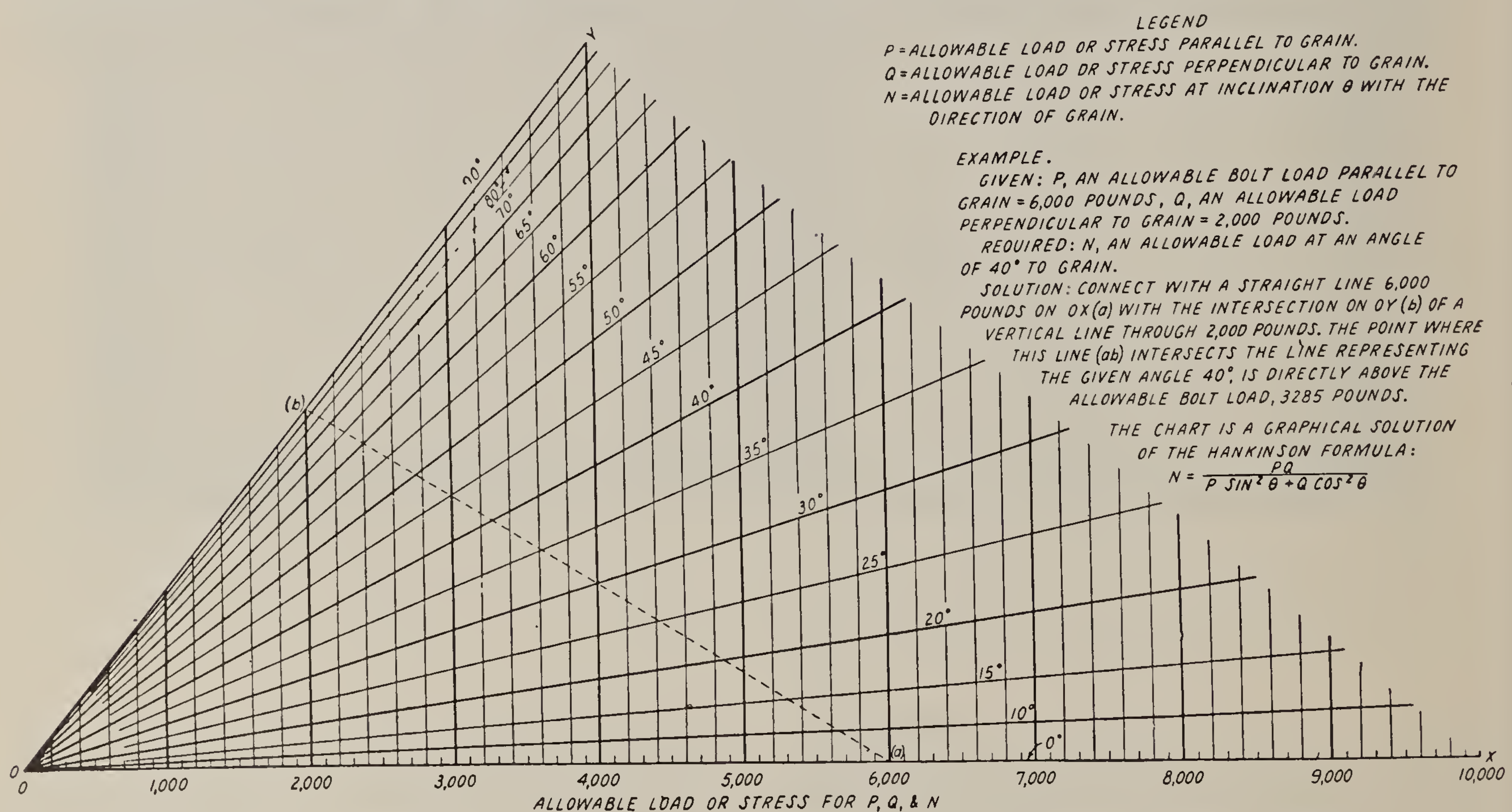

FIGURE 13–10.—Scholten nomograph for determining bolt-bearing strength of wood at various angles to the grain.

13.131. Safe Loads.—The safe loads for bolts bearing either parallel or perpendicular to the grain of the wood and spaced and alined correctly are given in table 13–6. These loads were developed from tests made at the Forest Products Laboratory *(13–2, 13–5)* and are of such a magnitude as to prevent undue permanent distortion in the joint under long-time loading. The ultimate load is obviously considerably greater but will occur at an excessively large distortion. For bolt sizes other than those listed in table 13–6, approximate loads may be obtained by interpolation. The loads for bolts acting at various angles between the parallel-to-grain and perpendicular-to-grain limits may be obtained by use of the nomograph shown in figure 13–10. The species corresponding to the various groups shown in table 13–6 are shown below:

SOFTWOODS

Group 1:
- Pine, ponderosa, sugar, Eastern white, and Western white
- Spruce, red, Sitka, and white
- White-cedar, Atlantic and Northern

Group 2:
- Douglas-fir (Rocky Mountain Region)
- Hemlock, Western
- Pine, red
- Redcedar, Western
- White-cedar, Port Orford
- Yellow-cedar, Alaska

Group 3:
- Baldcypress
- Douglas-fir (Coast Region)
- Larch, Western
- Pine, southern yellow
- Redwood
- Tamarack

HARDWOODS

Group 1:
- Ash, black
- Chestnut
- Yellow-poplar

Group 2:
- Elm, American and slippery
- Maple, soft (red and silver)
- Sweetgum
- Tupelo, black and water

Group 3:
- Ash, commercial white
- Beech
- Birch, sweet and yellow
- Elm, rock
- Maple, hard (black and sugar)
- Oak, commercial red and white

13.132. Details of Design.—The details of design required in the application of the values given in table 13–6 may be summarized as follows:

1. A load applied to only one end of a bolt, perpendicular to its axis, may be taken as one-half the symmetrical two-end load as given in table 13–6.

2. The center-to-center distance along the grain between bolts acting parallel to grain should be at least four times the bolt diameter. When the joint is in tension, the bolt nearest the end of a timber should be at least seven times the bolt diameter from the end of the timber for softwoods and five times for hardwoods. When the joint is in compression, the end margin may be four times the bolt diameter for both softwoods and hardwoods. Any decrease in these spacings and margins will decrease the load in about the same ratio.

3. For bolts bearing parallel to grain, the edge margin should be at least 1.5 times the bolt diameter. This, however, will usually be controlled by (a) the common practice of having an edge margin equal to one-half the distance between bolt rows and (b) the area requirements at the critical section. (The critical section is that section of the member, taken at right angles to the direction of load, which gives the maximum stress in the member based on the net area remaining after reducing it for bolt holes at that section.) For parallel-to-grain loading, the net area remaining at the critical section should be at least 80 percent of the total area in bearing under all the bolts in the particular joint under consideration for softwoods, and 100 percent for hardwoods.

4. For bolts bearing perpendicular to grain, the margin between the edge toward which the bolt is acting and the center of the bolt or bolts nearest this edge should be at least four times the bolt diameter. The margin at the opposite edge is relatively unimportant. The minimum center-to-center spacing of bolts in the across-the-grain direction for loads acting through metal side plates need only be sufficient to permit the tightening of the nuts. For wood side plates, the spacing is controlled by the rules applying to loads acting parallel to grain if the design load approaches the bolt-bearing capacity of the side plates. When the design load is less than the bolt-bearing capacity of the side plates, the spacing may be reduced below that required to develop their maximum capacity.

TABLE 13-6.—*Safe loads for common bolts loaded at both ends (double shear)*[1]

Bolts bearing parallel to the grain [2]

Size of bolt	Thickness of main timber	Softwoods Group[4] 1	Softwoods Group 2	Softwoods Group 3	Hardwoods Group 1	Hardwoods Group 2	Hardwoods Group 3
Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
½	1	400	500	650	462	600	750
	1½	600	750	966	694	900	1,114
	2	796	974	1,203	920	1,169	1,388
	2½	954	1,104	1,300	1,103	1,325	1,500
	3+	1,026	1,136	1,310	1,186	1,365	1,510
⅝	1	500	625	812	578	750	938
	1½	750	938	1,215	867	1,125	1,402
	2	1,000	1,245	1,595	1,156	1,495	1,840
	2½	1,244	1,520	1,880	1,437	1,825	2,170
	3	1,445	1,696	2,018	1,671	2,036	2,328
	3½	1,580	1,770	2,041	1,826	2,125	2,358
	4+	1,605	1,780	2,048	1,856	2,135	2,360
¾	1½	900	1,125	1,462	1,040	1,350	1,688
	2	1,200	1,500	1,942	1,388	1,800	2,240
	2½	1,500	1,868	2,380	1,735	2,240	2,746
	3	1,790	2,190	2,705	2,070	2,630	3,120
	3½	2,035	2,405	2,870	2,351	2,885	3,312
	4	2,230	2,540	2,940	2,580	3,048	3,394
	4½+	2,310	2,560	2,950	2,671	3,070	3,400
⅞	2	1,400	1,750	2,275	1,620	2,100	2,625
	3	2,100	2,609	3,310	2,428	3,132	3,820
	4	2,730	3,255	3,900	3,156	3,906	4,500
	5	3,115	3,478	4,012	3,602	4,174	4,630
	6+	3,150	3,484	4,012	3,640	4,180	4,630
1	2	1,600	2,000	2,600	1,850	2,400	3,000
	3	2,400	3,000	3,860	2,775	3,600	4,452
	4	3,182	3,898	4,810	3,680	4,675	5,550
	5	3,818	4,410	5,200	4,410	5,300	6,000
	6+	4,110	4,550	5,240	4,750	5,460	6,042
1¼	3	3,000	3,750	4,860	3,470	4,500	5,600
	4	4,000	4,980	6,380	4,620	5,980	7,360
	5	4,980	6,090	7,520	5,750	7,310	8,670
	6	5,780	6,790	8,060	6,690	8,150	9,300
	7	6,310	7,080	8,170	7,300	8,500	9,430
	8+	6,430	7,110	8,190	7,430	8,540	9,460

Bolts bearing perpendicular to the grain [3]

Size of bolt	Thickness of main timber	Softwoods Group[4] 1	Softwoods Group 2	Softwoods Group 3	Hardwoods Group 1	Hardwoods Group 2	Hardwoods Group 3
Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
½	1	126	168	231	147	210	336
	2	252	336	462	294	420	672
	3	378	504	693	441	630	970
	4	504	646	813	588	740	1,008
	5	536	------	------	626	------	------
⅝	2	285	380	522	332	475	760
	3	428	570	784	498	712	1,140
	4	570	760	1,040	665	946	1,415
	5	713	922	1,150	832	1,045	1,425
	6	760	------	------	888	------	------
¾	2	317	423	582	370	528	846
	3	476	635	873	556	794	1,270
	4	634	846	1,164	740	1,058	1,680
	5	793	1,056	1,434	925	1,304	1,905
	6	952	1,220	1,535	1,110	1,395	1,903
	7	1,020	1,230	------	1,189	------	------
⅞	2	350	467	642	408	583	933
	3	525	700	962	612	875	1,400
	4	700	933	1,284	817	1,167	1,867
	5	875	1,167	1,604	1,021	1,458	2,284
	6	1,050	1,400	1,885	1,225	1,714	2,475
	7	1,225	1,570	1,981	1,429	1,801	------
	8	1,306	1,583	------	1,524	------	------
1	2	381	508	698	445	635	1,015
	4	762	1,016	1,396	890	1,270	2,030
	6	1,144	1,525	2,095	1,334	1,905	2,932
	8	1,525	1,954	2,460	1,780	2,236	3,050
	10	1,620	------	------	1,892	------	------
1¼	4	890	1,190	1,635	1,040	1,490	2,380
	6	1,340	1,785	2,450	1,560	2,230	3,570
	8	1,785	2,380	3,260	2,080	2,960	4,430
	10	2,230	2,860	3,600	2,600	3,270	4,460
	12+	2,380	------	------	2,780	------	------

[1] The values given in this table represent pounds per bolt and apply to seasoned timbers used in a dry, inside location. For timbers occasionally wet but quickly dried, use three-fourths of the load listed; if they are damp or wet most of the time, use two-thirds of the load listed.

[2] These loads are for 3-member joints with metal splice plates. When wood splice plates are used, each being one-half the thickness of the main timber, 80 percent of these loads should be used.

[3] These loads apply for both wood and metal splice plates except that the safe load perpendicular to the grain should never exceed the safe load parallel to the grain for any given size of bolt or quality of timber.

[4] For species of wood included in each group, see tabulation given in section 13.131.

13.14. Connectors.

13.140. General.—Metal timber connectors are commonly used, in conjunction with bolts, at the joints of heavy timber structures. By increasing the total bearing area near the surfaces of the contact faces, they provide much greater shear resistance than can be had with bolts alone. In housing, most joint loads will be of such magnitude that the use of connectors is not required, but there may be occasional applications where the use of connectors is desirable.

13.141. Connector Types.—Several types of connectors are available. For house construction, it is probable that toothed rings, shear plates, claw plates, and small split rings would find the greatest application (fig. 13–11).

Split rings are inserted into precut grooves bored in the pieces with a power tool (fig. 13–11, *A*). Shear plates and claw plates are set into precut daps. The shear plate daps accomodate the entire connector, but the teeth of the claw plates must be forced into the wood below the limit of the dap. Toothed rings do

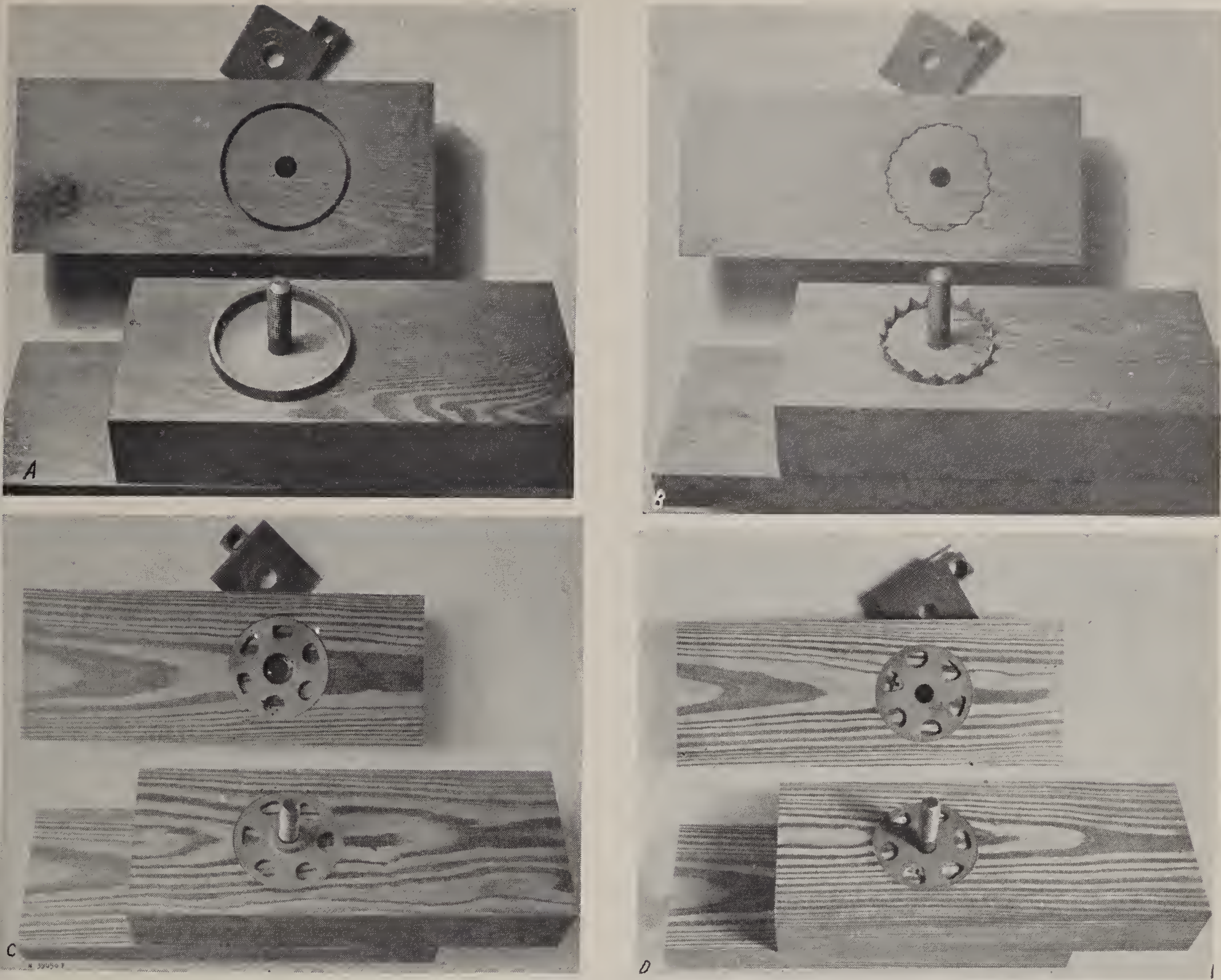

FIGURE 13–11.—Four types of connector assemblies. *A*, split-ring; *B*, toothed-ring; *C*, claw-plate; *D*, shear plate.

not require precut grooves, but are forced into the wood by pressure developed through the use of high-strength bolts.

Split rings and toothed rings are suitable only in wood-to-wood joints, whereas both shear plates and claw plates are suitable in either wood-to-wood or metal-to-wood joints. Shear-plate connectors, in addition, are especially useful in structures that are to be demounted and moved from place to place. The surface of the connector is flush with the face of the timber and thus has no projections to cause trouble in storage or shipment and, when once inserted in the timber, need not be removed when the structure is disassembled.

13.142. Safe Loads.—The load that can be carried by a connector in conjunction with a bolt is much greater than that which can be carried by a bolt of the same size. The basic long-time load for a 2-inch toothed-ring connector with a $\frac{1}{2}$-inch bolt, for example, is 1,100 pounds when it is bearing parallel to grain of a dry Douglas-fir piece at least 2 inches thick and 735 pounds when bearing perpendicular to the grain of a 2-inch Douglas-fir piece that has a width of at least $2\frac{5}{8}$ inches *(13–3)*. The comparable load on one end of a $\frac{1}{2}$-inch bolt used alone is 480 pounds parallel to the grain and 185 pounds perpendicular to grain (table 13–6). The relationship between the load for a bolt and that for a connector differs somewhat for different connectors, sizes of members, and species of wood, but the example is illustrative of the increased load capacity afforded by connectors.

Safe loads that may be carried by split rings, toothed rings, and claw plates have been established by the Forest Products Laboratory *(13–3)* and those for shear plates, as well as the other types, are given elsewhere *(13–4)*. The design loads given in reference *(13–4)* are approximately 20 percent higher than those established by the Forest Products Laboratory *(13–3)*, since the former are based on the increased stresses established during World War II by the War Production Board's Conservation Division in its Directive 29, National Emergency Specification for the Design, Fabrication, and Erection of Stress-grade Lumber and Its Fastenings for Buildings. It should be noted that, for a joint having two or more connectors spaced on a line parallel to the grain and with the load acting perpendicular to grain, the total load used should be equal to the full load of one connector plus one-third this amount for each additional connector.

13.143. Details of Connector Design.—Engineering design utilizing timber connectors is covered in detail in references *(13–3)* and *(13–4)*. Adequate presentation of this information is not considered to come within the scope of this manual.

13.15. Plates and Strapping.—Plates or anchors of various types may be used in housing for anchorage of walls or rafters or for connection of parts. The load-carrying capacity of such anchors depends primarily upon the load-carrying capacity of the fastenings (usually nails) attaching them to the wood members.

Metal straps are sometimes used to provide resistance against uplift at the rafter-wall connection and sometimes also to anchor walls to foundations. The load-carrying capacity of straps used in these ways also depends upon the load-carrying capacity of the nails or other fastenings attaching them to the wood members.

Anchors or straps are generally so arranged that the nails are loaded in shear rather than in direct withdrawal. The loads that can be carried by the nails, or the number of nails required to give adequate load-carrying capacity to an anchor or strap, may then be computed by the methods shown in section 13.112. It should be noted that the safe loads computed by the equation given in that section may be increased by 25 percent because of the fact that metal is being fastened to wood.

Care should be taken that the anchor or strap in itself has sufficient strength to carry the loads required of it. Thus, in straps, adequate cross-sectional area should remain after deductions are made for the holes.

13.16. Tie Rods.—Rafters, as a result of the roof loads they sustain, exert a thrust or outward push on the walls which support them. This thrust is ordinarily resisted by means of ceiling joists or rafter ties of wood, but in some instances it may be desirable to resist this thrust by means of steel tie rods.

Such ties, whether of steel or wood, must have adequate strength to resist the thrust loads imposed on them. The fastenings of such ties must also be adequate. The nails fastening a ceiling joist to a rafter, for example, must be adequate in both size and number to resist the loads at the joint. Nails used in this way are usually stressed in shear, and the methods given in section 13.112 may be used to determine the number and size of nails required.

Where metal tie rods are used, they may apply their loads to the wood members either through plates attached to the members by wood screws or bolts, or through plates that bear directly on the members. With fastened plates, adequate screw-holding power in lateral resistance must be supplied, and the number and size of screws may be determined by the methods of section 13.220. Plates bearing directly on members must have adequate stiffness and area to prevent crushing under the tie-rod ends.

13.2. GLUE JOINTS.

13.20. General.—Glue joints in prefabricated housing, especially where the stressed-cover type of construction is employed, must develop strength enough to meet the structural requirements and maintain this strength under the use conditions for which they are intended. To produce such joints, the wood must be at the proper moisture content at the time of gluing, the wood surfaces must be properly prepared, and good glue and good gluing technique must be employed (ch. 11).

Only when side grain is glued to side grain can glue joints in general closely approach the strength of the wood. Often it becomes necessary, however, to employ various types of joints

where considerable end grain is exposed on the surfaces to be joined. Examples of such joints are miter, dowel, and serrated, hook, and other types of scarf joints (fig. 13–1). These joints do not develop the full strength of the wood, but with proper technique can be made strong enough for many purposes.

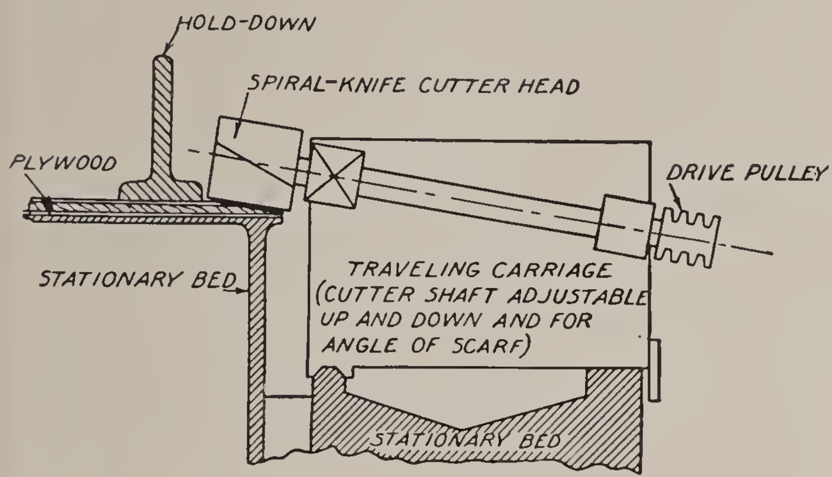

FIGURE 13–12.—Schematic drawing of machining setup for cutting scarf joints in plywood. Cutter head moves on carriage along edge of plywood, which is held firmly on stationary bed.

13.21. Scarf Joints.—Scarf joints are ordinarily employed to produce members of required length with retention of a reasonable percentage of the strength of an uncut piece. There are several types of scarf joints, such as the plain scarf, hooked scarf, and serrated scarf. Glued scarf joints with a relatively long slope are probably the only end joints that can develop tensile strength approximating that of the wood closely enough for use in stressed coverings .Greatest economy of material is effected by using steep slope; however, strength considerations demand flatter slope. Glued scarfs that are depended on for strength should be cut so that the joint surfaces are as nearly parallel as possible to the grain of the wood, are smooth, and fit true. A machine for cutting scarfs in plywood is shown in figure 13–12.

In applying gluing pressure, precautions must be taken to prevent end slippage. Efforts should be made to keep the parts in proper alinement, as illustrated by figure 13–13. A small amount of overlap, as illustrated, is desirable and insures that the joint will receive adequate gluing pressure.

In scarf gluing of thin plywood, application of fluid pressure is preferred to the use of solid platens, as it is more likely to provide close contact between the surfaces even if there are slight imperfections in the fit of the joint. A piece of fire hose inflated with steam to provide fluid pressure has been used successfully in such presses (fig. 13–14).

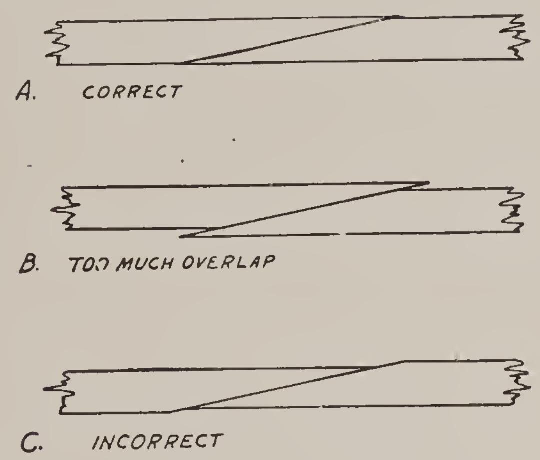

FIGURE 13–13.—*A*, correct with slight overlap; *B*, acceptable, but needs trimming off of overlapped surfaces; and *C*, incorrect method of alining scarf joints for gluing.

Slopes of 1 in 10 to 1 in 15 are recommended for scarfing plywood or solid wood where the scarf is required to develop high strength.

13.22. Butt Joints.—It is practically impossible with present day adhesives to make glue joints between end-grain surfaces sufficiently strong

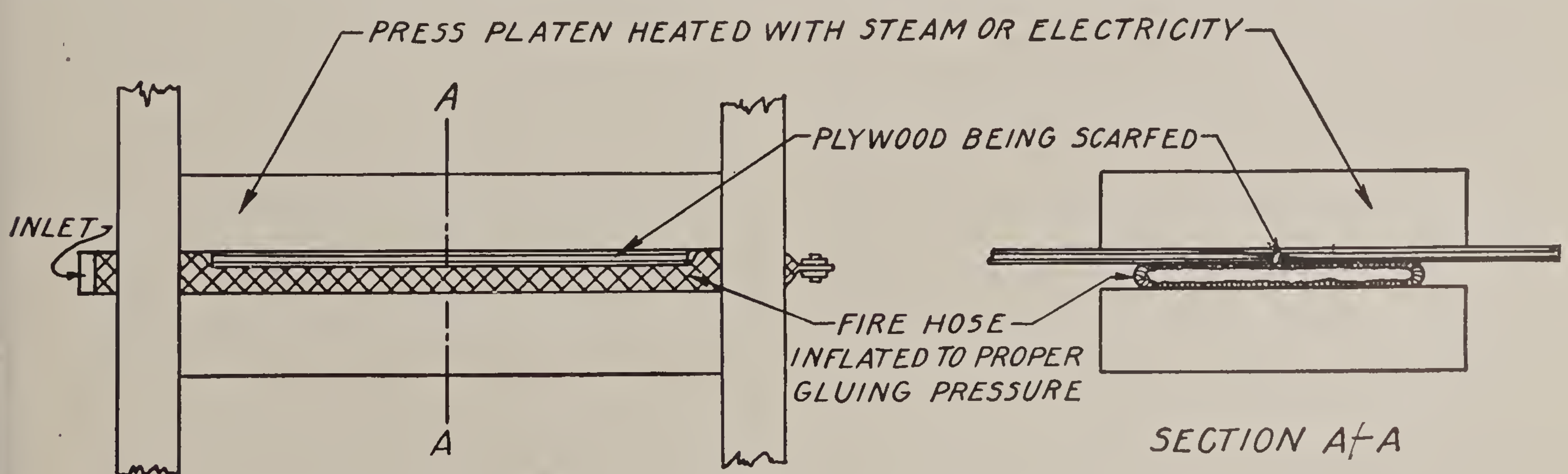

FIGURE 13–14.—Fire-hose pneumatic press for gluing plywood scarf joints.

and durable to meet the requirements of ordinary service. With the very best gluing technique, not more than about 25 percent of the tensile strength of the wood parallel with the grain can be obtained in butt joints.

Joints of end to side grain are also difficult to glue properly and cannot be depended on to furnish high strength. In service, they are subjected to severe stresses as a result of unequal dimensional changes in the two members of the joint with changes in moisture content. It is, therefore, necessary to use irregular shapes of joints, such as dowels, tenons, or other devices, to reinforce the joints and to get side-grain to side-grain contact and also larger gluing surfaces. All such joints should be carefully protected against changes in moisture content.

13.23. Side-grain Joints.—With most species of wood, plain glue joints between side-grain surfaces can be made, for practical purposes, as strong as the wood itself in shear parallel to the grain, tension across the grain, and cleavage. Various shaped joints, such as the tongue-and-groove, present the thoretical advantage of larger gluing surfaces than the plain joints, but they do not produce higher strength with most woods. Furthermore, the theoretical advantage of larger gluing surfaces is often lost, wholly or in part, because the shaped joints are more difficult to machine than straight, plain joints for obtaining a perfect fit of the parts. Lack of contact may make the effective holding area actually smaller on a shaped joint than on a flat surface and thus reduce, rather than increase, the strength. Only under circumstances where the gluing conditions are not well controlled and the joints are weak do the larger contact surfaces of well-fitted joints improve strength. The principal advantage of tongue-and-groove and other shaped joints is that the parts are more quickly alined in the clamps or press. A shallow tongue-and-groove is usually as useful in this respect as a deeper cut and involves less waste of material.

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PREFABRICATION OPERATIONS

14.0. GENERAL.—The techniques of house prefabrication differ in important respects, depending upon the type of house being built and the materials used. Basically, these differences arise from the characteristics of the materials and their adaptability to prefabrication, the principles of which are the same regardless of the type of house being assembled. The basic objective of all prefabrication is to produce standardized parts, such as a modular panel, a series of room-size sections, or a three-dimensional unit assembly consisting of one or more rooms, that will permit assembly at the site without resort to the cutting and shaping operations characteristic of conventional on-site construction.

Conventional construction presumes all materials are brought to the site to be cut, fitted, framed, and finished. Actually, some parts are prefabricated, such as doors, windows, cases, cabinets, and stairways. Where stressed-cover construction or sandwich materials are employed in the factory, work often includes complete roof and floor parts as well as walls, ceilings, and partitions. Differences in materials and construction are many, including differences in size of framing, type of covering, machining, gluing, painting, treatment with preservatives, insulation, and the various means employed to assemble the standardized parts of the house.

Regardless of techniques and materials, the ultimate goal is a house that will meet its occupants' requirements for long-time service and comfort. It must be carefully planned in all details. It is not sufficient, structurally, that the panels meet certain strength tests; nor that a unique method of joining panels together or of anchoring roof to walls or walls to floor and foundation has been evolved. It is the sum of all these, plus adequate attention to such factors as insulation, ventilation, finish, decay and fire hazards, quality and condition of materials, and careful workmanship, that finally determines the functional adequacy of the house.

The purpose of this discussion is not to recommend or advocate the adoption of any particular technique having to do with a specific prefabrication operation. It is recognized that the prefabricator is limited by the equipment, labor, materials, and other essentials at his command in his choice of construction. The market in which his product may be used may also present limitations. The objective of this discussion is rather to point out and relate the advantages and disadvantages of the techniques discussed here to the basic principles of wood utilization and the inherent advantages and limitations of wood, plywood, and other wood-base materials as discussed in preceding chapters.

This discussion of prefabrication operations is based to a large extent upon observation and assistance gained in visits to factories representing a broad cross section of the nation's prefabricators, as well as upon more than a decade of research and experimentation by the Forest Products Laboratory in this field of construction. Virtually without exception, the builders with whom the subject was discussed made their plans and specifications freely available. Acknowledgment of this assistance is made elsewhere in this manual. It is desired to emphasize here, however, that the use made herein of the information obtained is in no way intended to reflect upon the practices and techniques employed by any individual builder or firm, since very often other considerations and limitations than can be discussed here are reflected in his choice of materials and methods.

14.1. DESIGN CONSIDERATIONS.

14.10. General.—The term "design," as used herein, is limited to the engineering phases of design. The emphasis, therefore, is upon considerations of strength, durability, adequacy of joints and fastenings, and generally satisfactory functional performance of the units and

the finished structure. These considerations may also involve such factors as the properties of materials used and installation of insulation and vapor barriers for comfort and to avoid maintenance difficulties.

14.11. Design Systems.—The cardinal principle of all assembly-line fabrication is the production of large numbers of identical units. In prefabricated house production, this principle is approached in various ways, depending upon the kind of house being built and upon the builder's approach to his problem. Basically, however, the houses must be reduced to a minimum number of different parts, each so designed that it can be used interchangeably with others of its particular size and construction and will fit into its proper place in any house of like design. Obviously, to achieve such identity and interchangeability calls for a system of design.

Prefabricators have devised various design systems by which the elements of their houses are produced in quantity to meet these requirements. The basis of all such systems is one or more standardized parts of fixed dimensions. Such parts may be a modular (fixed-width) panel, multiples of which determine house dimensions (fig. 14–1); a series of wall, roof, and ceiling sections (figs. 14–2 and 14–3) designed to fit a particular size and type of house; or, approaching the problem from another direction, a system of columns, posts, trusses, or other load-bearing members to which vari-

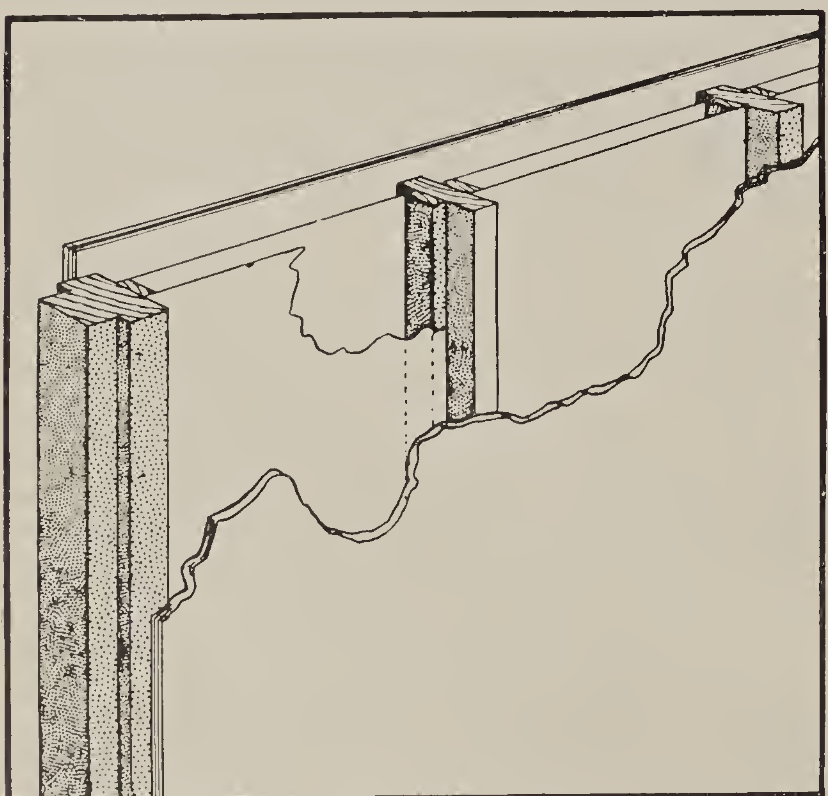


FIGURE 14–1. — Wall panel with stressed covering, showing framework, covers, and two curtains of foil insulation.

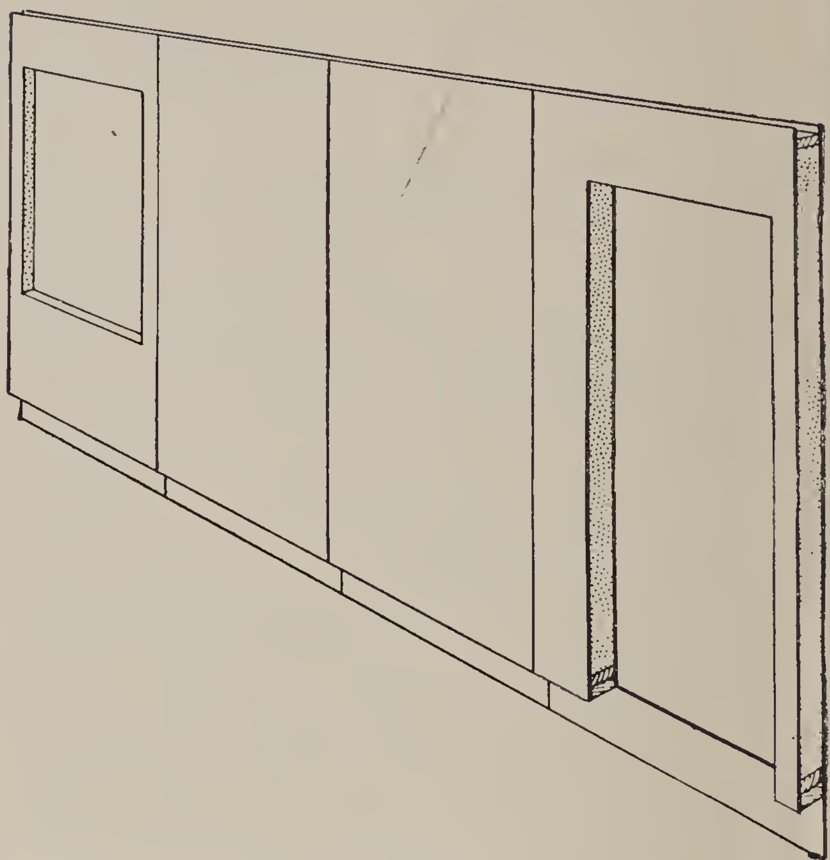


FIGURE 14–2.—Room-length section of stressed-cover construction, showing door and window openings.

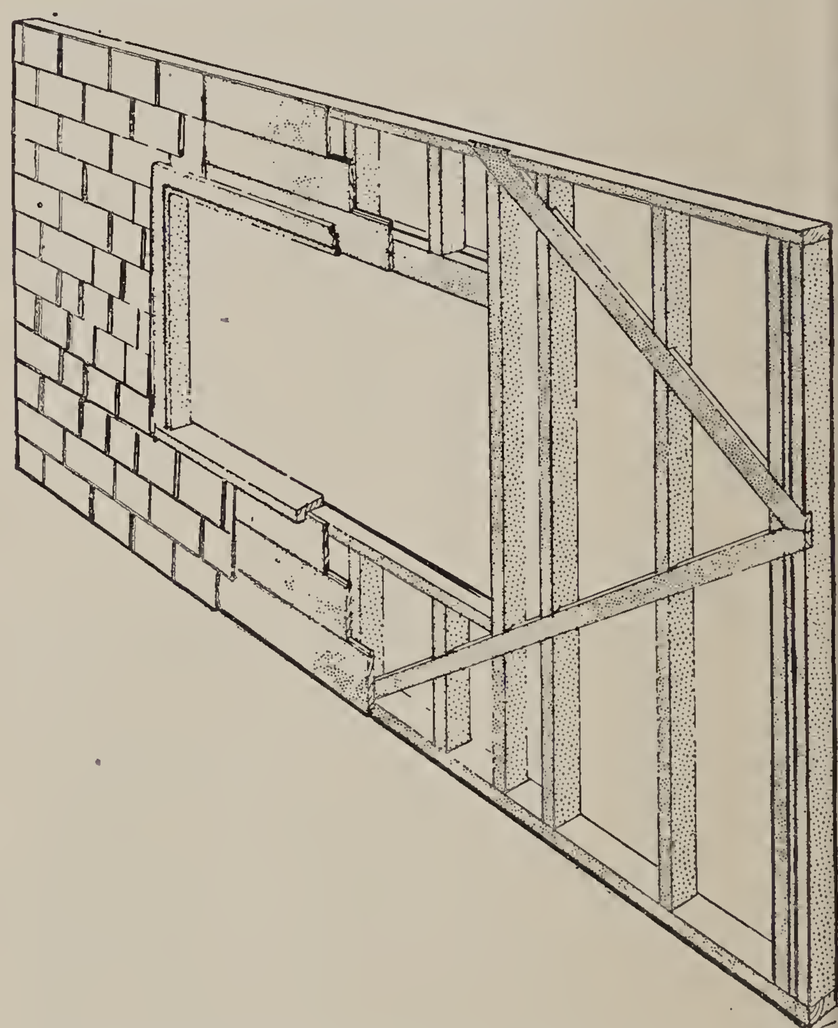


FIGURE 14–3.—Nailed-construction wall section of room length, showing studding, bracing, sheathing, and exterior shingles.

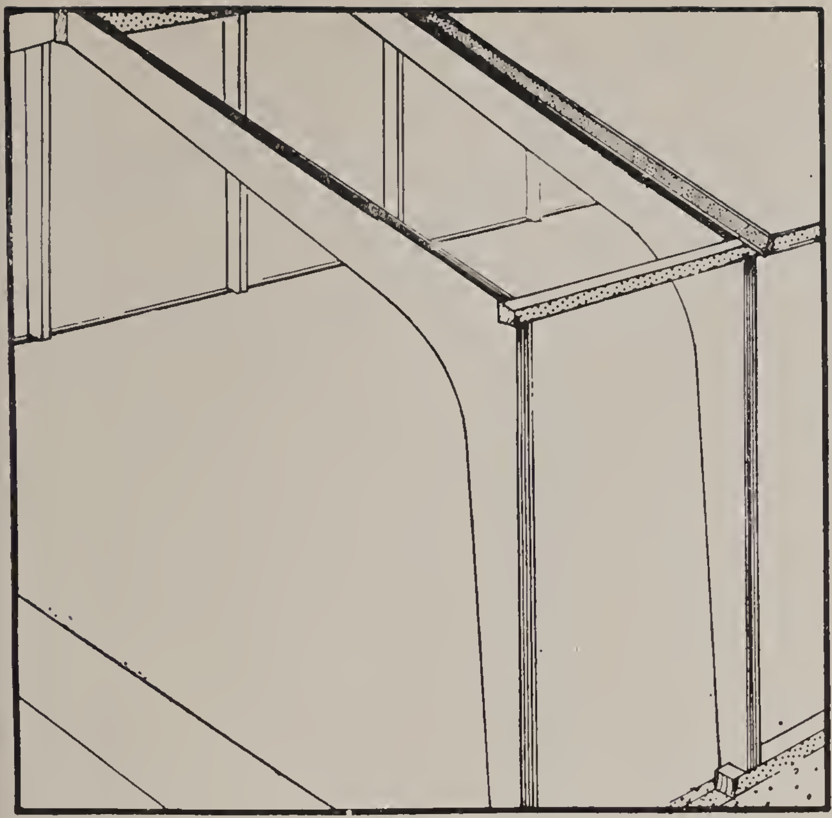


FIGURE 14–4.—Arch-type load-bearing member.

ous types of curtain-wall materials are attached (figs. 14–4 and 14–5).

14.110. Ready-cut Houses. — For many years, houses have been built according to the so-called ready-cut system using materials cut to length and otherwise machined at a mill. Framing, sheathing, fastenings, and other materials usually are prepared and stenciled, by the material supplier, with identifying part marks according to established house designs. Actual construction is done on the site by methods identical with those by which conventional houses are built. While some labor and material savings are undoubtedly effected by this method, it does not constitute prefabrication in the sense of assembly-line production of interchangeable units. The ready-cut house is mentioned here because it represents a step in the evolution of the prefabricated house rather than because it belongs in this category.

14.111. Panelized Construction.—The basic unit of most systems of prefabricated house construction is the panel. As the term is used in this manual, a panel is an integral construction unit consisting essentially of both load-bearing and covering materials. It usually also contains insulation and moisture-vapor barriers; and either provision is made at the factory for the insertion or attachment of windows, doors, electrical conduit, pipe, and other accessories at the building site, or else such accessories are installed at the plant. Sometimes interior partition panels, especiall yif nonload-bearing, contain built-in cabinets, bookcases, and other furniture.

14.1110. Factory-made Panels with Framing of Conventional Size.—Panels can be fabricated with a framework and sheathing of sizes common in conventional site construction (fig. 14–3). As in conventionally built houses, the framework is capable of carrying all the loads. Frequently, plywood is nailed or glued to one or both sides of the studding and to the top and bottom plates of wall panels; by using plywood, fabricating time is reduced and a panel is produced that has greater resistance to racking loads than is achieved with lumber sheathing. Finish siding may be installed at the factory, but is often applied at the site. The completed panel, depending on its size, may weight upwards of a ton.

Since panels of this type are an adaptation of conventional construction, their design is based upon standard building practices for conventional houses. Nominal 2 by 4 studs are spaced 16 inches on center in wall panels; floor panels usually conform to the spacing, depth, and span requirements for joists as established for approved conventional construction. Usually, in this system of prefabricated housing, factory assembly of panels is limited to those

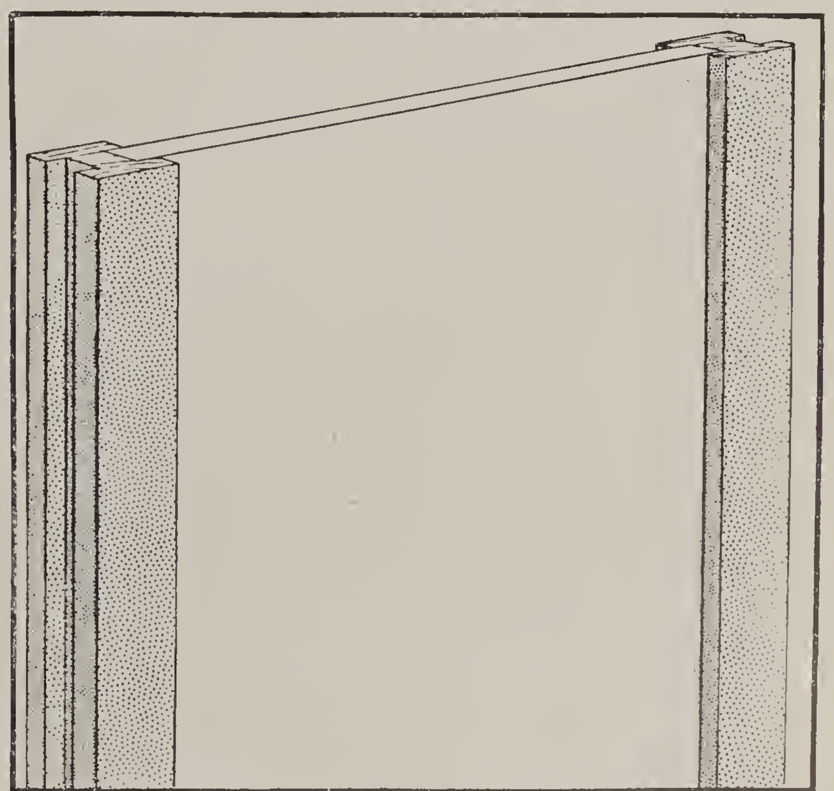


FIGURE 14–5.—Column-type load-bearing members with panelized curtain-wall material. Cover is fitted into grooves in load-bearing members.

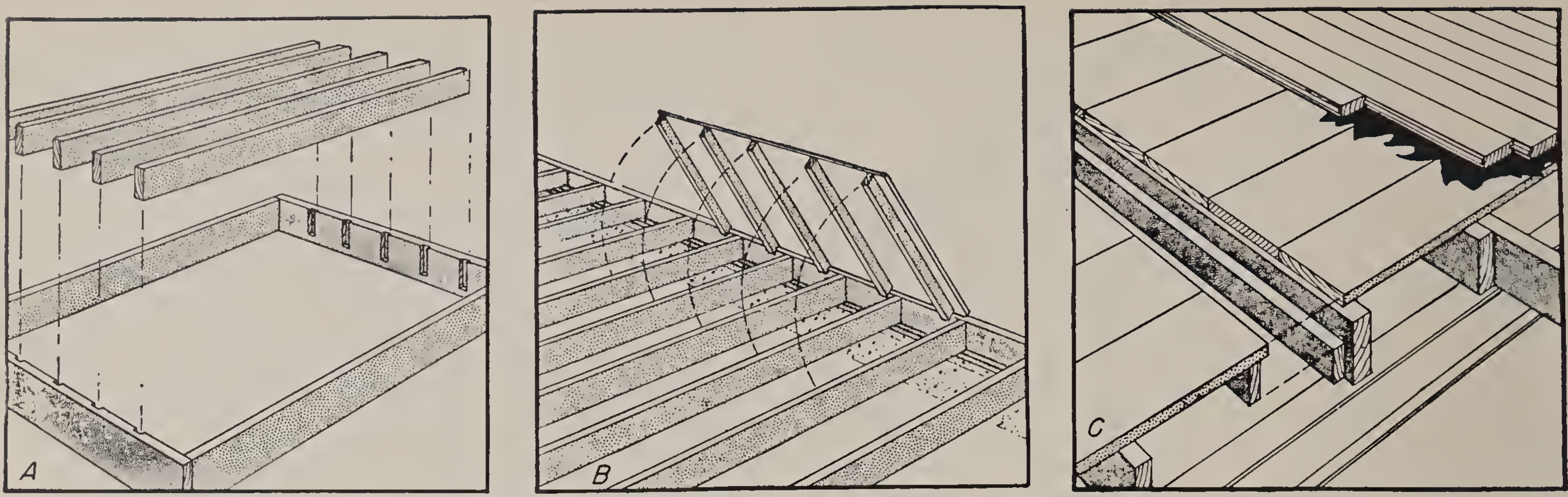


FIGURE 14–6.—Three methods of flooring panelization. *A*, floor panel with grooved headers in which shallower joists are fitted; *B*, conventional joist construction to which floor panels are spiked laterally to the joist: *C*, panelized floor sections fitted with half joists on one side to permit attachment of panels to each other by lateral spiking.

in walls, partitions, and less frequently, floors and ceilings. Various ingenious methods of panelization have been developed by prefabricators (fig. 14–6).

A major problem in nailed panel design using full-size framing is that of excessive use of material to facilitate attachment of panels. As shown in figure 14–6, *C*, it is necessary to double up joists at points where floor panels adjoin. The panel cleats shown in figure 14–6, *B*, also constitute excess material. Similarly, wall-panel studs are usually doubled up at points where the panels adjoin. Figure 14–7 illustrates excessive use of material in wall framing due in large part to panelization of the wall.

14.11100. Strength of Nailed Panelized Construction.—From the strength standpoint, nailed panelized construction is probably overdesigned. Since it is an adaptation of conventional construction, its design is based upon long-established construction practices and rules of thumb rather than upon engineering principles. While they have stood the tests of time, such structures are generally conceded to be overdesigned. Strength tests of structural elements of conventional houses have been made by the National Bureau of Standards and the Forest Products Laboratory *(14–4, 14–5, 14–9,* and *14–10)*.

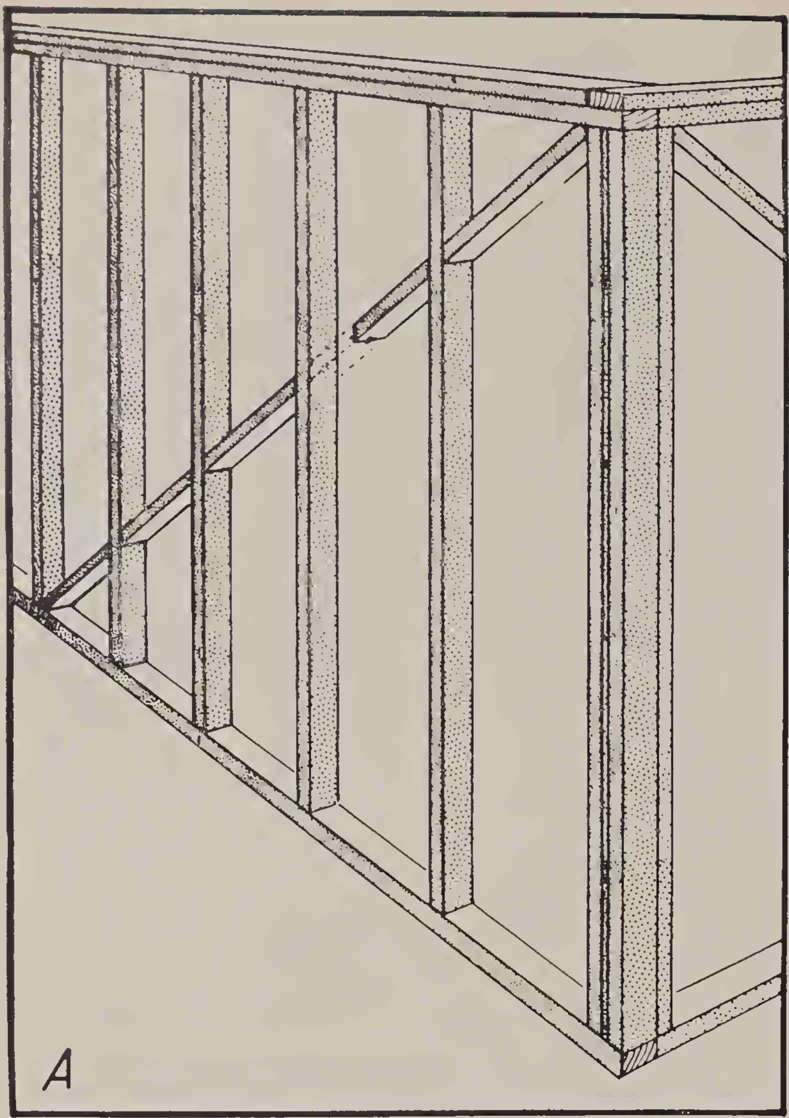
The strength and rigidity required in framed walls are obtained wth sheathing, bracing, or a combination of the two. The commonly used horizontal lumber sheathing without bracing affords little bracing effect under racking loads, and additional bracing is required to obtain adequate rigidity. The use of diagonal lumber sheathing, however, is quite effective in producing the desired stiffness. Plywood well nailed or glued to the studs produces excellent results, and fiberboard sheathing, if well nailed and properly used, is entirely adequate.

The two types of bracing commonly used in conjunction with sheathing are cut-in and let-in. Cut-in bracing (fig. 14–8, *A*) affords but little added rigidity and strength to the structure, because the bracing lacks the continuity necessary to transmit loads adequately. Let-in bracing (fig. 14–8, *B*), on the other hand, has been shown to be quite effective and some added improvement can be realized if the sheathing is nailed to the let-in bracing as well as to the studs.

The superiority of diagonal over horizontal sheathing and of let-in over cut-in bracing is indicated in figure 14–9, in which are shown the strength and rigidity of walls sheathed in various ways when tested under racking loads at the Forest Products Laboratory.

14.1111. Panels with Stressed Covers.—A panel with stressed covers may be defined as a structural element the covering of which acts integrally with its framing members to resist bending loads. The sheathing, therefore, not only furnishes coverage but carries part of the load. Such a panel commonly has several longitudinal members, which constitute the studs or joists and to which are attached headers and top and bottom covers of plywood. The difficulty of adequately attaching many other types of

FIGURE 14–7.—Excessive framing of an L-shaped building resulting from adaptation of conventional framing to panelized assembly. Panels meeting at right angles created a framing problem that the builder met by using more studs than would be necessary in a conventionally built house.



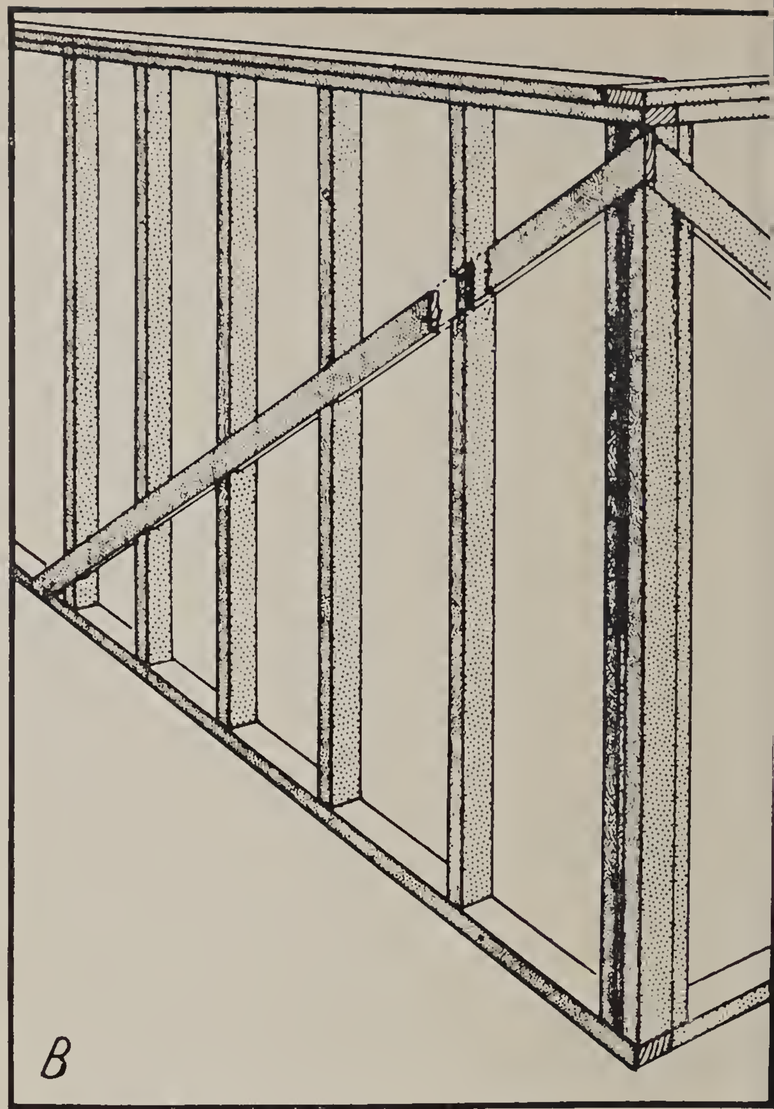


FIGURE 14–8.—Two types of wall bracing commonly used. *A*, cut-in bracing, consisting of 2- by 4-inch pieces fitted between the studs at an angle of approximately 45° with the horizontal and in a line from top to bottom plates; *B*, let-in bracing, consisting generally of a 1- by 4-inch piece set into notches in the studs and continuous from top to bottom.

covering materials to the longitudinal members makes them generally unsuitable. The methods of design given later apply specifically to panels having plywood covers, although they may be adapted to panels covered with other materials. The stiffness of the covering material governs the spacing of the longitudinal members; the panel cannot be considered to be a stressed-cover panel if the clear distance between longitudinal members exceeds certain established limits, since, beyond these limits, the cover would buckle even under design loads. With certain modifications, accepted engineering formulas can be used to design stressed-cover panels for strength and stiffness.

There are certain construction features that must be observed if satisfactory and safe panels are to be made:

1. The covering must be well glued to the frame. Even small unglued spots in the joints cause weakness, because of concentration of stress, out of all proportion to their size. Likewise, the glue bonds between plies of the covering must be well made.

2. The longitudinal members of the frame should be at least twice as thick as the covering itself.

3. Headers are essential when relatively thin, high longitudinal members, such as joists, are used.

Any means of fastening the covering to the longitudinal members that is less rigid than gluing (such as nailing) cannot be considered to give a panel with stressed covers.

14.11110. Design of Flat Panels with Stressed Covers for Strength and Stiffness.—The behavior of long thin plates under compressive loads in the direction of their length and with various side conditions furnishes certain conceptions as to the action of the thin coverings on panels and suggests how to design to take advantage of the strength of the covering. Studies have in-

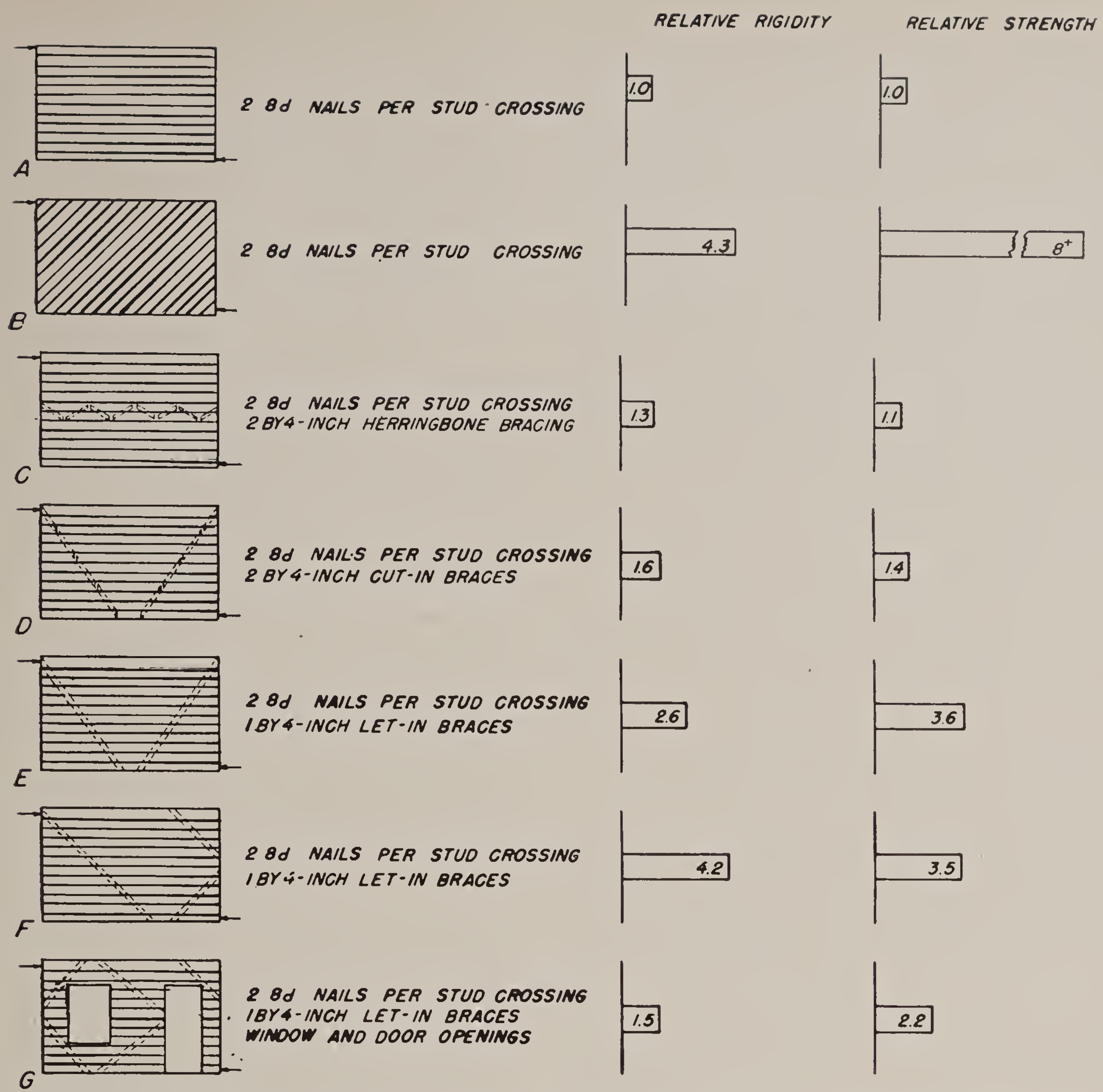


FIGURE 14–9.—Comparison of the strength and rigidity of a horizontally sheathed, unbraced wall with walls sheathed and braced in various ways. *A*, horizontal sheathing, unbraced; *B*, diagonal sheathing, unbraced; *C*, *D*, *E*, *F*, and *G*, various types of bracing.

dicated that, if the width between longitudinal members is doubled, the stress to cause buckling will be divided by 4, everything else being constant; and that the allowable distance between longitudinal members to prevent buckling of the covers, everything else remaining constant, will vary as the thickness of the covering. As the spacing between framing members is increased, the allowable load on a panel is reduced because of two effects: (1) a smaller proportion of the cover is considered to be effective in transmitting load; and (2) the allowable stresses in the cover are reduced from a certain value to two-thirds that value. Beyond a certain limiting spacing, the panel cannot be considered to be a stressed-cover panel.

The stressed-cover panel must be designed to have adequate longitudinal shear strength as well as bending strength and stiffness. The critical section in shear usually occurs at the joints between the framing members and the covering or within the covering above the framing members. More rarely, if checks are present, the framing members may fail in shear. Allowable stresses in shear between framing members and plywood covers or within the plywood covers are low, so that shear is frequently critical in a stressed-cover panel.

14.111100. Method of Calculating Panel Stiffness and Strength.—The method devised by the Forest Products Laboratory for calculating the strength and stiffness of stressed-cover panels having plywood covers is explained in detail in reference *(14–8)*. Briefly, the method is as follows:

In calculating the strength and stiffness of a plywood panel, any clear width of covering in excess of b between any two longitudinal members should be neglected. Panels with a clear distance between longitudinal members over $2b$ should not be considered as having stressed covering. The value of b shall be determined by the following formulas:

For three plies:

$$b = 31h\sqrt{\frac{h}{\text{parallel plies thickness}}}$$

For five or more plies:

$$b = 36h\sqrt{\frac{h}{\text{parallel plies thickness}}}$$

Where b is the basic width between longitudinal members (clear distance, not center to center), and h is the thickness of the plywood cover.

With b determined for plywood as above, the strength and stiffness of the panel should be determined from the strength values for clear wood given in table 5–1. First calculate the moment of inertia of the section, neglecting the cross plies and all covering in excess of b. Then calculate the stiffness, using the modulus of elasticity for the species taken from table 5–1. In calculating the safe strength for spacing of longitudinal members one-half b or less, use for high-grade plywood on the compressive face 85 percent, and for a medium grade of plywood 75 percent, of the basic stress in compression parallel to the grain, increased when used in a continuously dry location by 25 percent.

When the clear distance between the longitudinal members is greater than one-half b, reduce the stress uniformly from that allowed at one-half b to two-thirds this amount at a spacing of b; for spacings from b to $2b$, use the same stress as would be used at a spacing of b.

In calculating the strength on the tension face, use the basic stress in extreme fiber in bending (table 5–1) and proceed as above.

The allowable load on the panel as determined by shear on the joints between the longitudinal members and the plywood or in the first joint within the plywood immediately above the longitudinal members may be calculated by use of the ordinary engineering formula for shear on any plane of a beam and safe values of shear stress as given by the methods described in section 5.4.

14.11111. Effect of Openings on Strength of Stressed-cover Panels.—Since the covering of a stressed-cover panel is designed to carry a portion of the total load imposed on the panel, the effect of openings cut through the stressed covers must be considered in computing the strength and stiffness of the panel. Such openings may range from small holes through which electrical conduit and pipe are passed to comparatively large openings such as are required for heating ducts and cold-air returns.

The reduction in either strength or stiffness cannot be predicted from the reduction in moment of inertia caused by the holes. In general, the reduction in strength is not so great as would be indicated by the reduction in moment of inertia, while the stiffness at design loads appears to be little affected by holes in the stressed covers.

Lacking a theoretical basis for predicting strength reduction or for designing reinforcing around openings, it appears necessary to indicate types of reinforcement found satisfactory for a particular type of panel to serve as a guide for the design of other panels. The following remarks are based on the results of tests on panels consisting of nominal 2- by 6-inch joists spaced 23 inches on center with end headers and having a top cover of five-ply plywood five-eighths inch thick with the face grain perpendicular to panel length, and bottom cover of three-ply plywood three-eighths inch thick with face grain parallel to panel length. The top cover consisted of five pieces joined together with glued butt joints and the bottom cover was of two or three pieces joined together with glued scarf joints having a slope of about 1 in 12. The covers were nailed and glued to the joists.

All holes were cut through both top and bottom covers. Holes not larger than 6 inches in diameter at the center of the span or holes 12 inches in diameter not farther than one-sixth the span length from the support apparently have little effect on either maximum strength or stiffness at design loads even without reinforcement. Holes of small size, therefore, may generally be permitted without reinforcement and without considering the strength as being reduced.

Two 12-inch round or square holes at the center of the span, however, reduced the strength about 25 percent, although the stiffness at design loads was reduced only about 5 percent. Reinforcement of such panels with 3/8-inch, three-ply Douglas-fir plywood glued to top and bottom covers over the full width between longitudinal members and extending 18 inches each way from the centers of the holes gave satisfactory results. So, too, did reinforcement consisting of 1 5/8- by 5 3/8- by 27-inch pieces glued to the longitudinal members and the covers and pieces of the same cross section placed transversely adjacent to the holes. Somewhat less effective reinforcement was provided by nailing 1- by 5 3/8-inch pieces to the covers adjacent to the holes and transverse to the longitudinal members.

Openings of larger size, 21 by 30 inches, such as might be required for a cold-air return, were adequately reinforced by securely spiking an additional joist, extending the full span length, to the outside joist adjacent to the hole. In construction, therefore, such reinforcement may be provided by spiking the joist adjacent to the opening to the house sill. Inadequate nailing reduces the effectiveness of this method of reinforcement.

14.11112. Effect of Joints in Stressed Covers.—The design of long panels requires the use, in the covers, either of specially made plywood longer than standard or of joints in the covering. Two types of joints are generally possible—a scarf joint or a simple butt joint either with or without a splice plate.

Simple butt joints placed directly over a header of the same thickness as the other framing members give satisfactory results when used on the compression side of a panel. On the tension side, however, such joints seriously impair the strength of the panel even though stiffness is but little affected. The use of splice plates on one side of the joint, even when as wide as 5 5/8 inches, does not give satisfactory results. Wider splice plates would be more effective, but it is not known what width would be required and it is probable that inordinately wide plates would be needed to produce results approaching those for an unspliced panel.

Butt joints, therefore, are not satisfactory for use on the tension face of a stressed-cover panel or for use on either face of a panel subject to reversal of stress. For such covers, splices should be made with scarf joints (section 13.31) having a slope of 1 in 12 or flatter.

14.11113. Nailed vs. Pressure-glued Panels.—Adequate, uniformly distributed gluing pressure is fundamental to the production of high-quality glue joints (sec. 11.3). The development of such pressure is most easily attained by means of mechanical pressure exerted as in a gluing press or with jack screws. Lack of such means requires the use of nails to develop gluing pressure.

There is no theoretical basis for computing the nail size and spacing required to furnish adequate gluing pressure for gluing any particular combination of plywood and framing member. Tests of stressed-cover panels have indicated, however, that certain combinations as shown in table 14–1 give satisfactory results.

Table 14–1.—*Size and spacing of nails for various thicknesses of plywood as used in nail gluing of stressed-cover panels*

Plywood thickness	Nail	Spacing
Inch		*Inches*
1/4	1 1/4-inch brads	3
3/8	Sixpenny finishing	3
5/8	Sixpenny common	6

Other spacings, sizes, and kinds of nails than those given in table 14–1 might also prove satisfactory, but there is no way of predicting results.

While it has been found that good glue joints can be produced by nail gluing (sec. 14.4510), the method of applying pressure during the setting of the glue appears to be of less importance than other factors (sec. 11.3) involved in gluing technique, such as: (1) proper surfacing of framing members to insure complete and uniform contact between gluing sur-

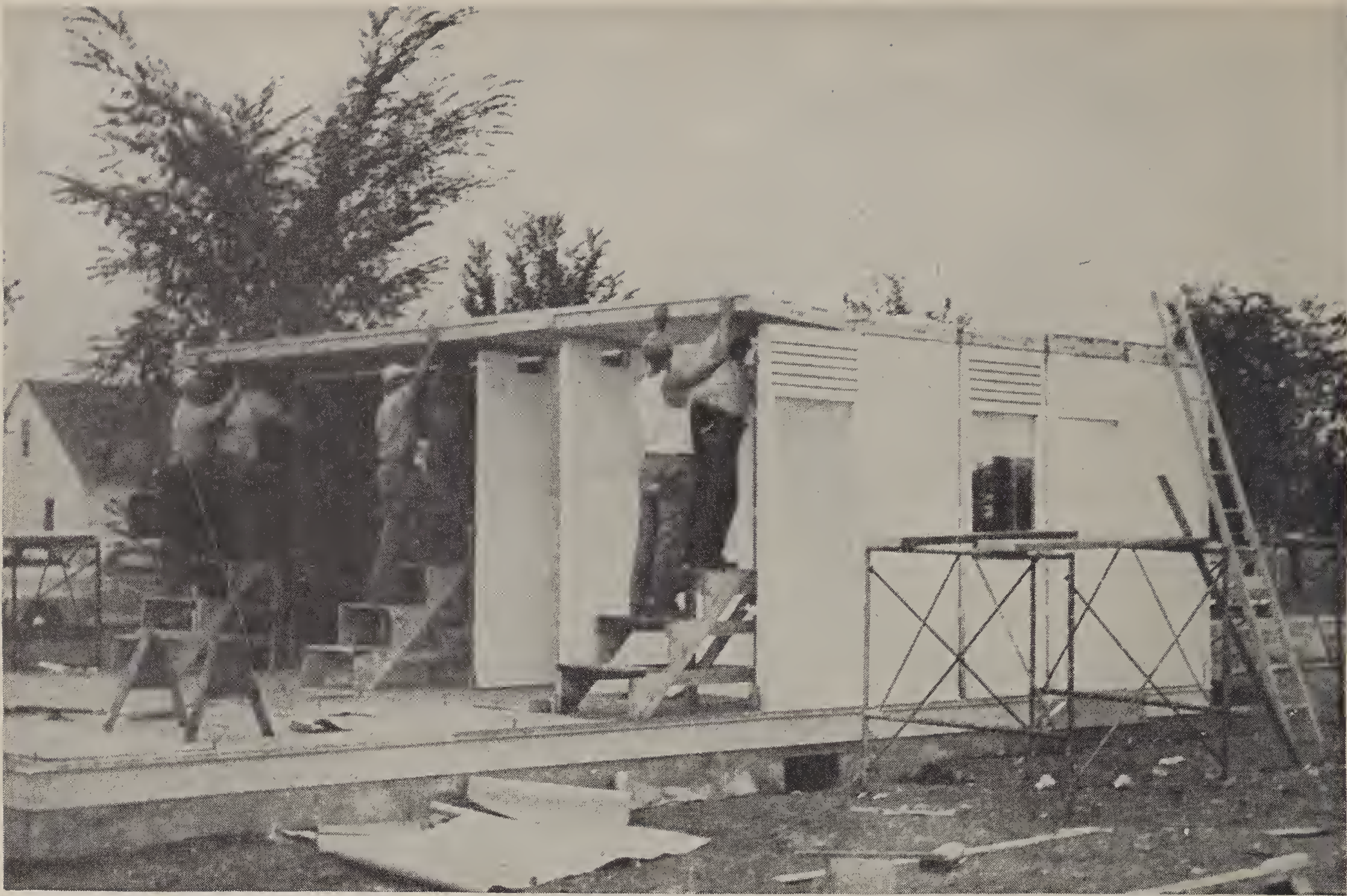


FIGURE 14-10.—Long stressed-cover plywood roof panels being erected in a prefabricated house.

faces; (2) adequate width of framing members to insure sufficient glue area; (3) proper moisture content of the lumber (definite moisture limitations are necessary to limit the shrinking or swelling of framing members and plywood, since dimensional changes induce high stresses in the glue joint); (4) type and quality of glue; (5) proper mixing and spreading of glue; and (6) elapsed time between spreading of the glue and application of pressure.

Experience indicates that good glue joints are more likely when pressure-glued than when nail-glued. In general, it would appear from the results of tests that good joints can be made by either method.

The use of brads or finishing nails where they give satisfactory results is desirable in order that they may be set and thus improve the appearance of the surface.

14.11114. Behavior of Paint Films over Joints in Stressed Covers.—In the many instances where an unbroken painted wall surface is desirable, the problem of concealing the joints between adjacent plywood panels has proven very difficult. The normal dimensional changes that occur in the plywood with moisture content changes cause the paint film at the joint to crack unless the movement of the plywood can be restrained within the limits of the elastic properties of the paint.

Simply nailing plywood to framing members does not give a joint sufficiently rigid to prevent a slight opening between plywood cover pieces and, thus, cracking of the paint at the joint. Several techniques have, however, been developed which prevent or minimize such cracking.

A simple method which has given good results consists in gluing the covers to the studs and plates and gluing a strip of balloon cloth about 2 inches wide over the joint. Nailing a plywood strip with the face grain of the strip at right angles to the stud and gluing the abutting plywood covers to the strip has also given good results. Thin metal, as perforated aluminum or black iron, may be used in place of the plywood strip, but the special techniques required to obtain a good bond between the wood and metal may make use of this method

FIGURE 14–11.—Sectional prefabricated gable end being erected. This gable is prefabricated in three sections and shipped to the building site for assembly.

undesirable. Gluing a strip of wood into rabbeted edges of the plywood cover pieces in conjunction with the gluing of the plywood cover to the stud has given indications of producing acceptable results. The gluing of strips of balloon silk over the joints, in conjunction with other methods, should increase their efficiency. Machining the edges of adjoining plywood sheets to form a shiplap joint, and gluing this joint, should also assist in preventing the cracking of paint films.

The use of wallpaper will present much the same problem as has been discussed above, but it is believed that the techniques which are satisfactory for paint films would also be satisfactory for wallpaper.

14.12. Roof Design.—Various types of pitched and flat roofs have been utilized by prefabricators in the design of their houses. From the standpoint of strength and serviceability, all have their advantages. Some are less adaptable to shop prefabrication in the form of panels than others, and in such cases the prefabricator may resort to precutting of rafters and roof boards for conventional site fabrication. The flat roof and the simple gable roof are the most readily prefabricated types.

Stressed-cover panels are particularly suitable for flat roofs because such panels are essentially box beams, thus providing both coverage and strength. Stressed-cover roof panels with spans of as much as 24 feet are employed in flat roofs (fig. 14–10). Because of their length, the long framing members in these panels are sometimes lap spliced or, preferably, scarf jointed. Fabrication of such panels calls for special care and equipment (sec. 14.40). Their design for strength is explained in sec-

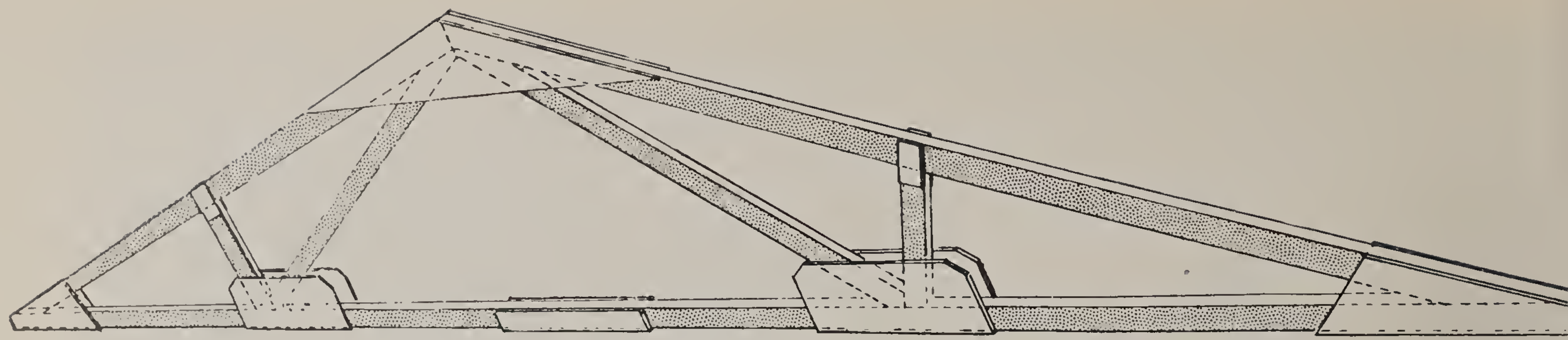


FIGURE 14–12.—Common truss for use in prefabricated housing.

tion 14.11110. Because deflection under load is the critical factor in employment of such long panels, stiffness is generally the most important property for which these panels are designed. In climates where ventilation is necessary, such roof panels can be ventilated as described in section 8.220.

Pitched roofs can be designed for partial or complete prefabrication. Usually the gable ends are prefabricated (fig. 14–11) in sections for quick assembly at the site. Design of gable ends is generally a simple matter of plywood or other sheathing fastened to studding with nails or glue. The roof is often of stressed-cover construction; plywood or other coverage is often fastened to rafters on one side only, and the roofing applied on the site. To aid in assembly, roof panels may incorporate headers

FIGURE 14–13.—Special truss-type construction devised for roof of a 1½-story house. Note ventilating holes in plywood web of peak.

FIGURE 14–14.—Arch-type roof construction. Model shows vertical members of roof supports joined with plywood gusset plates.

that are attached at an angle so that headers of opposite panels meet flush to form a ridgepole when spiked together.

Various types of trusses have been adapted to roof construction of prefabricated houses, especially small houses. Generally, the purpose of such trusses is to eliminate the need for a center bearing partition in the house and thereby permit greater flexibility in room layout. Truss designs used range from the common type shown in figure 14–12 to such highly specialized designs as that shown in figure 14–13. Laminated and built-up arches of special design have also been devised for use in small houses (figs. 14–4 and 14–14).

The common truss shown in figure 14–12 consists of single upper and lower chords with diagonals. All joints are lapped with plywood gusset plates nail-glued in place.

The truss-type construction shown in figure 14–13 was designed to permit maximum utilization of second-story space for rooms. Shop-fabricated in sections, this construction represents economy of materials as compared with conventional roof construction; the members are spaced 4 feet on center as compared with conventional 16-inch spacing of rafters. The plywood web in the peak section contributes to stiffness, as do the plywood sections at the eaves. Between these sections, the upper chord is increased in depth for stiffness and bending strength, as shown in figure 14–13.

The arch-type roof design shown in figure 14–14 is well adapted to small houses because it permits greater flexibility of room arrangement on a limited floor area, up to the maximum width of the house. The unorthdox design of the roof supports includes gusset plates glued at the joints. A steel plate bolted in place connects the two trusses at the ridge. The model illustrated in figure 14–14 demonstrates the light construction of this house, developed

FIGURE 14–15.—Wood posts and beams of a basementless house. Note concrete base for post.

primarily for use in warm climates. What is in effect an 8-foot module is used throughout to make most economical use of materials; especially 4- by 8-foot plywood. Arches are left exposed on the interior side in the finished house, except below window-sill level of the walls, where the space is devoted to cabinets.

14.13. Framed Floors.—Wood framed floors are commonly used in basementless houses. The foundation walls are generally of masonry starting in the ground below the frost line and extending at least 18 inches above grade. The floor joists or floor panels are set on top of this wall. Masonry piers or wood posts are sometimes used in lieu of the wall or as intermediate points of floor support (fig. 14–15). Sills or beams span from pier to pier and support the floor joists or panels and the exterior walls. The zone below the floor and above the ground is commonly called the crawl space.

Soil moisture is one of the serious problems in houses having crawl spaces, largely because of the danger of decay in joists and sills (fig. 14–16). Moisture from this source also may cause floors to warp, stressed plywood covering to delaminate, and can even result in condensation of moisture on walls and roof spaces.

All types of soil are not equally troublesome, some types being naturally dry whereas others are very damp and transmit considerable quantities of moisture. If the crawl space is at a lower level than the finished grade outside of the building, rain water will tend to keep the soil wet.

Crawl spaces should be properly ventilated. To accomplish this, openings are provided in the foundation wall or skirting. Such openings should have a total net area of not less than 2 square feet for each 100 linear feet of wall, plus ½ square foot for each 100 square feet of building area, with not less than one opening on each side of the building. Ventilation does not always provide adequate protection (fig. 14–17). In some instances, ground plantings

FIGURE 14–16.—Assembling paneled subfloor on foundation of basementless house.

cut off or interfere with air movements and sometimes the householder closes the vents in cold weather and neglects to open them the following spring. As the ground below the house is protected, it is slow to freeze and can give up moisture in considerable quantities even in very cold weather. Adequate ventilation to remove this moisture may cause water and sewer pipes to freeze, and is certain to cause cold floors. Closing the vents in cold weather is nevertheless objectionable because it prevents the escape of moisture.

Corrective measures involve:

1. Reducing the amount of moisture that can rise from the soil by covering all soil area in the crawl space with some material highly resistant to vapor transmission. Roll roofing is one such material that is relatively inexpensive and can be laid over the ground and held down with stones or bricks.

2. Provision for some cross ventilation through the crawl space. Such ventilation in the colder climates makes necessary the following:

a. Protection of water and sewer pipes with insulation to prevent freezing.
b. Protection of the floor with insulation, to prevent cold floors.

With protection such as roll roofing over the soil, little moisture will rise through the joints of the roofing and, consequently, very little ventilation is required. In houses in which the crawl space is kept warm during the winter by heating pipes, ventilation should be provided, especially for summer conditions.

14.14. Insulating Materials.—Insulating materials are available in a variety of types (sec. 8.112). In selecting types suited for prefabricated construction, all the factors influencing its use must be considered, such as first cost, availa-

FIGURE 14–17.—Ventilators installed in foundation of a basementless house. Where such louvered ventilators are used, it is necessary to provide more openings because air movement is greatly impeded. Simple screening is preferable where good ventilation is desired with a minimum number of openings.

bility, ease of installation, ability to remain in place, thickness of insulation compared to thickness of panel, thermal properties, and weight.

Where production-line methods are followed, the flexible or blanket type of insulation can generally be used to good advantage for wall, ceiling, and floor construction. It is available in a variety of thicknesses, and is covered on one or both sides with paper. It can be tacked or otherwise fastened between framing members (fig. 14–18). The paper covering supports it so that it will not settle. The covering may also be treated to serve as a vapor barrier. The blanket types are generally made from materials that are light in weight and have good thermal properties.

The batt type is suitable for use where the wall space is completely filled with insulation. It should be placed under slight lateral pressure to prevent subsequent settlement. When batt insulation is used in ceiling and floor panels, it usually only partially fills the space and provision should be made to hold the batts in position so that they will not become displaced during handling operations. A separate vapor barrier is required, since no covering sheet is supplied with batts.

The fill type can be substituted for the batt type in wall construction, and the same precautions apply to installation procedure for it.

Insulating fiberboards can be precut to the required sizes to fit between framing members. Two or more pieces may be stapled together to obtain the thickness necessary to meet an established over-all resistance to heat transmission. Being rigid and self-supporting, this type of material will not settle in a wall. Separate vapor barriers are preferred, but a good bar-

FIGURE 14–18.—Stapling blanket insulation on site.

rier may be obtained by coating the surface of the side towards the room with asphalt. Fiberboards should be securely fastened in place.

Reflective insulation is available in a number of types. One type is made by cementing aluminum foil to a strong back of paper and is obtainable with foil on one or both faces of the paper. The latter is preferred when used as a curtain in the framing spaces. It is highly vapor-resistant and no additional vapor barrier is required. Multiple curtains may be needed to obtain the over-all resistance to heat transmission desired in cold climates.

Crumpled aluminum foil in multiple sheets is another type of reflective insulation. This type requires a separate vapor barrier. Aluminum foil is also mounted on corrugated or honeycombed paper in such a way as to obtain a construction with multiple air spaces between sheets of insulation. Here again, separate vapor barriers are required, as there are likely to be numerous holes and breaks in the foil surface by the time it is fastened in place.

Reflective insulation is not limited to aluminum. Thin sheet steel coated with a noncorrosive material is also available. When it is properly installed, no additional vapor barrier is required.

In addition to the types described, a number of others have merit, among which are cork blocks, corrugated boards, processed paper blankets, honeycombed paper products, and honeycombed materials made from glass.

14.15. Vapor Barriers to Prevent Condensation.—The purpose and function of vapor barriers are described in section 8.23. It is advantageous to have the vapor barriers as an integral part of the insulating material, since this simplifies the assembly operation. The material or coating used for the barrier should be one that has been proven by test to have the required resistance to vapor transmission. Holes or breaks in the barrier should be cause for rejection. The barrier should be attached to the framing members in such a manner as to prevent vapor from passing between the barrier and the framing member. Asphalt paint or mastic may be necessary as a sealing agent at this joint (fig. 14–19).

Separate vapor barriers can be selected from materials that are high in vapor resistance, and can generally be counted upon to be more efficient than integral barriers (fig. 14–20). Where wall facing materials, such as plywood, are glued to the framing members, the barriers must fit between the framing members. If the barrier is cut about 4 inches larger than the width and length of the opening that it covers, the excess width and length can be turned up at an angle of 90° to form flanges that fit against the framing members around the opening. It may be fastened in place by stapling through the flanges, if attached to the narrow face of the studs, or held in place with cleats if attached to the sides of the stud. Vapor barriers should always be on the warm side of the insulation.

14.16. Thermal Factors Affecting Stressed-cover Panel Thickness.—When developing designs for stressed-cover prefabricated construction, the designer first determines the size of the framing members and wall thickness required to support all loads imposed. In a stressed-plywood wall, for example, he may find that the required strength can be obtained in a wall

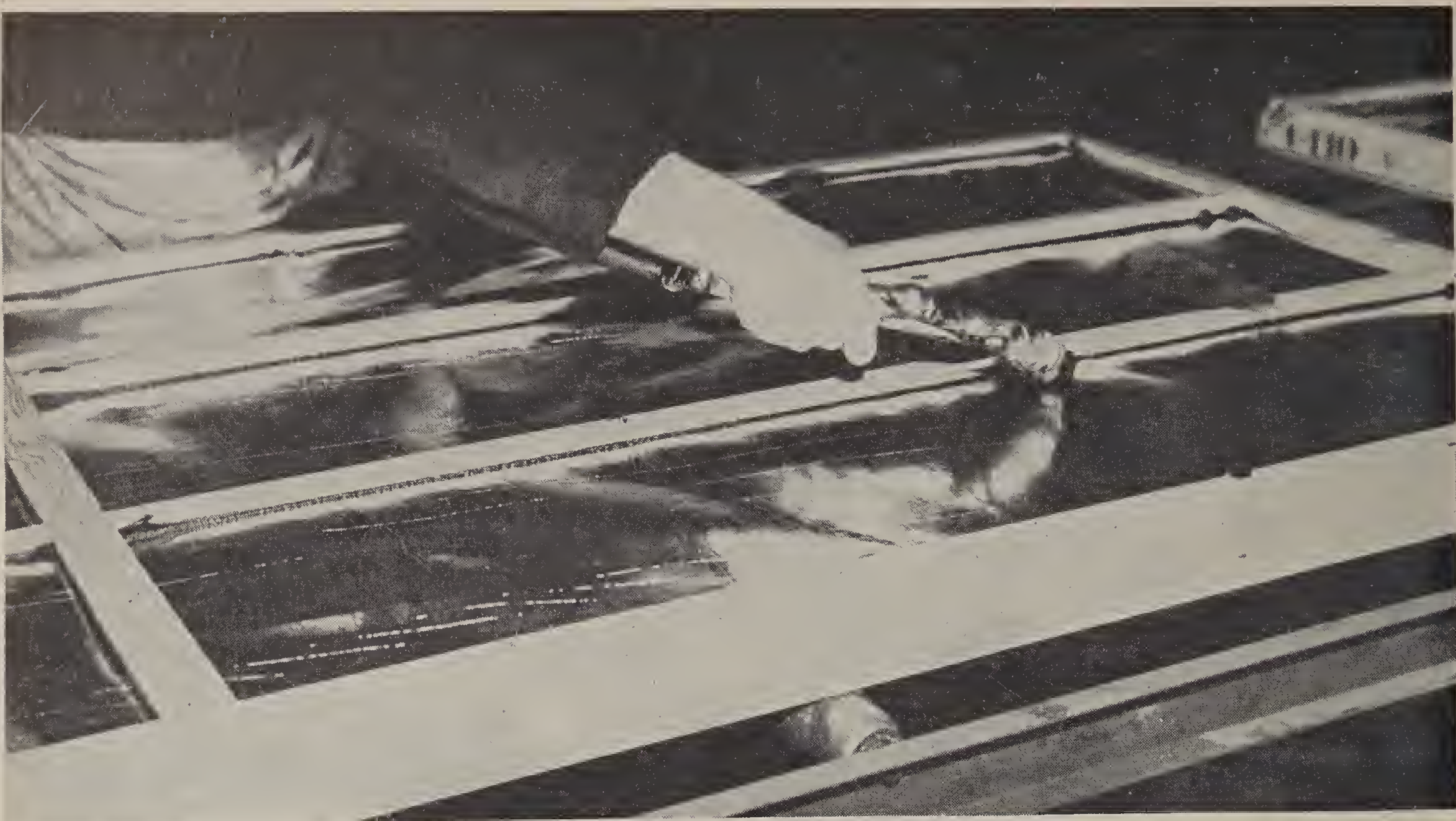


FIGURE 14–19.—Sealing the joint between a vapor barrier and framing members with mastic applied with a gun similar to those used for greasing automobiles.

thickness of 2 inches. Other considerations, however, may mean that thicker walls are desirable.

14.160. Dirt Patterns.—The lath marks or dirt patterns sometimes seen on walls and ceilings of inside surfaces of exterior walls, on ceilings below cold attics, and on outside walls of houses painted a light color are caused by slight differences in surface temperatures that occur when the heat loss through framing members or other parts is not substantially the same as that through the space between the members. This temperature difference leaves parts of the surface cooler than others, and the cooler parts attract more dirt particles floating in the air than do the warmer parts. Temperature differences sufficient to cause these dirt patterns can be very slight. Such marks will be most pronounced where no insulation is used. They will be least in evidence when the coefficient of heat transmission through the framing members is the same as that through the space between members. Since the framing members are characteristically narrow in prefabricated construction, the heat loss through these members during cold weather may be higher than is desirable for the wall as a whole.

A study of the surface temperature values shown in tables 8–1 through 8–3 establishes the fact that the surface temperature over framing members varies with the width of the member, and that the U value for a framing member 2 inches deep is considerably below

FIGURE 14–20.—Installing continuous vapor barrier over studs before applying wall sheathing.

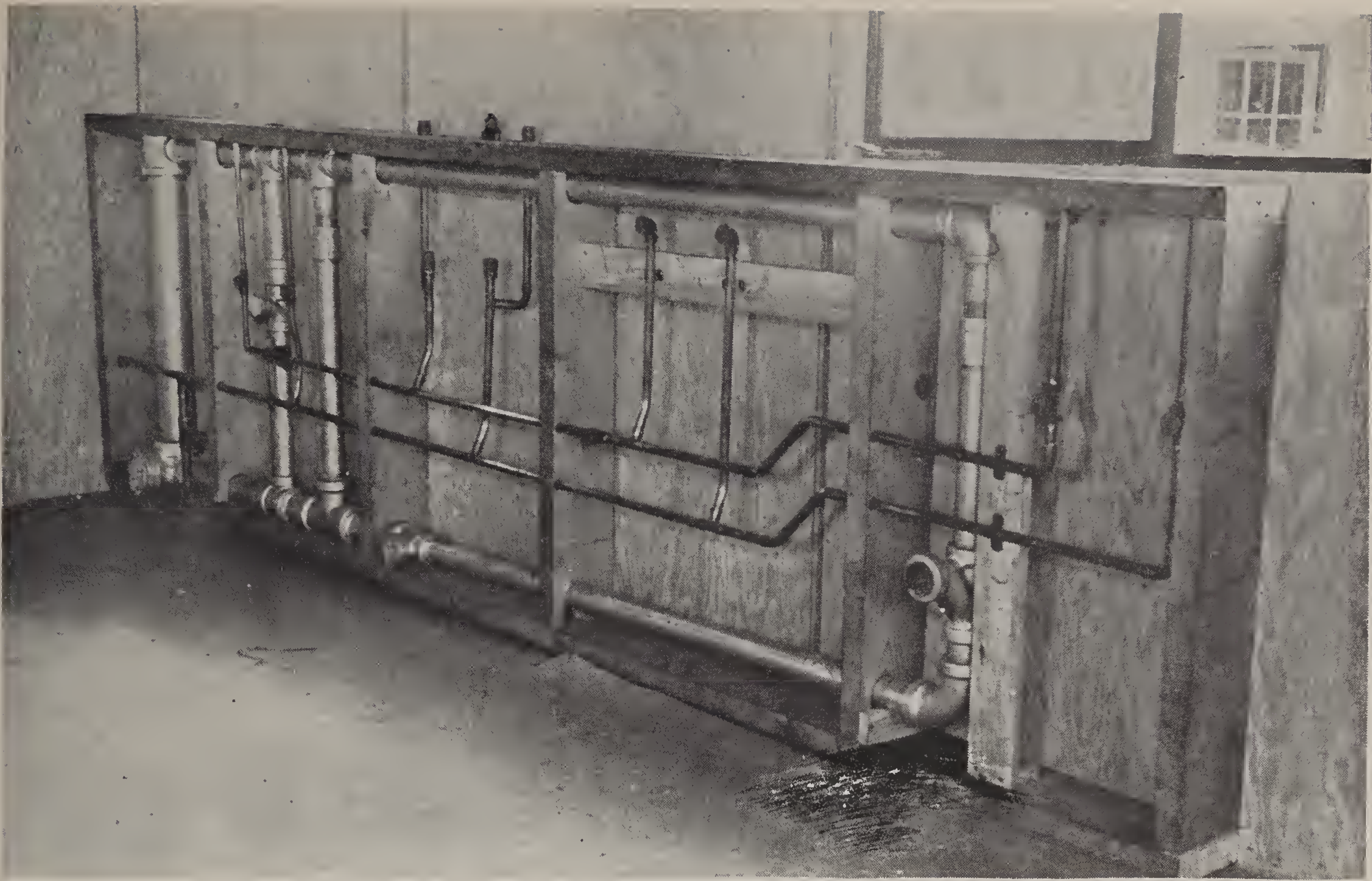


FIGURE 14–21.—Panel unit containing piping for kitchen and bathroom plumbing.

that which falls in the desired range for comfort (sec. 8.10). A 2½-inch member has a U value nearly equal to that of a wall space having one-half inch of insulation and one air space. Insofar as dirt pattern is affected by balancing the U values at the studs with those of the wall spaces between studs, it appears that framing members 2½ to 3 inches deep balance closely with one-half inch of insulation and one air space between the framing members. At least 2 inches of insulation are required, however, to obtain a surface temperature in the desired comfort range. If comfort is the first consideration, the dirt pattern must be accepted; if dirt pattern is the first consideration, comfort and fuel economy must be sacrificed.

Nails used to attach finished wall materials to frames, or bolts and other metal fastenings used at joints of panels, may also create a dirt pattern that outlines each such fastening. In thin walls, or where long nails are used, condensation may collect over a nail head and cause not only a dirt pattern but a rust spot that cannot be cleaned off. Gluing the inner wall surfacing material to the frames without using nails for pressure eliminates such trouble caused by the nails. Insofar as possible, joints and connections should also be made without the use of bolts or metal connectors to avoid dirt patterns and rust stains.

Dirt patterns also appear on outside walls over nails and fastenings, most noticeably on large, smooth surfaces painted in light colors. These can be avoided by the same measures that apply to inside walls.

14.161. Insulation Around Pipes.—Water supply pipes, sink wastes, and other parts of the plumbing system affect panel thickness where installed at the factory. Since they may be damaged by freezing temperatures, they should be located in inside partitions wherever possible. Some prefabricators design special panels for plumbing pipes (figure 14–21). When it is necessary to locate them in outside walls, all insulation used should be between the pipes and the exterior wall surface; no insulation should be placed between the pipes and the inside wall surface, nor should insulation be wrapped entirely around the pipes.

FIGURE 14–22.—Room-width fiberboard panel in place. Size of wallboard sheet eliminates need for treatment of seams except at corners of room and at ceiling joint.

14.17. Joint Design.—Joint design, always a problem in the design of any structure, is especially important in prefabricated houses. Not only does it markedly affect the strength of such structures, but it also governs to a great extent the degree to which parts are interchangeable and the ease with which the structure can be erected. Of basic importance in these respects are the joints between panels and those by which the walls and partitions are attached to the roof and foundation. Obviously, the method of fastening the joints and the kinds of fastenings used require careful analysis in prefabricated house design. The basic principles of joints and fastenings are discussed in chapter 13.

In this section, three types of joints are discussed: (1) those between panels; (2) those connecting the walls and floors to foundations; and (3) those attaching roofs to walls.

14.170. Panel Joints.—The problem of attaching panels together is basically the same whether the panels are modular or specially fabricated in room-size lengths for a particular design of house. In fact, where a material of standard width, such as plywood, is used for coverage, the room-size sectional panel does not escape entirely from one problem of joint design, that of concealing the joint lines in the finished product. This problem, while a purely esthetic one, has probably received as much attention as any other involved in design of prefabricated house joints; some prefabricators have gone to great lengths to conceal the joint lines, while others have compromised with necessity by making a virtue of them with moldings, V-joints, or insert strips that accent the junction.

The problem of concealing or exploiting panel joints for esthetic purposes is mentioned here not because of its critical importance to the

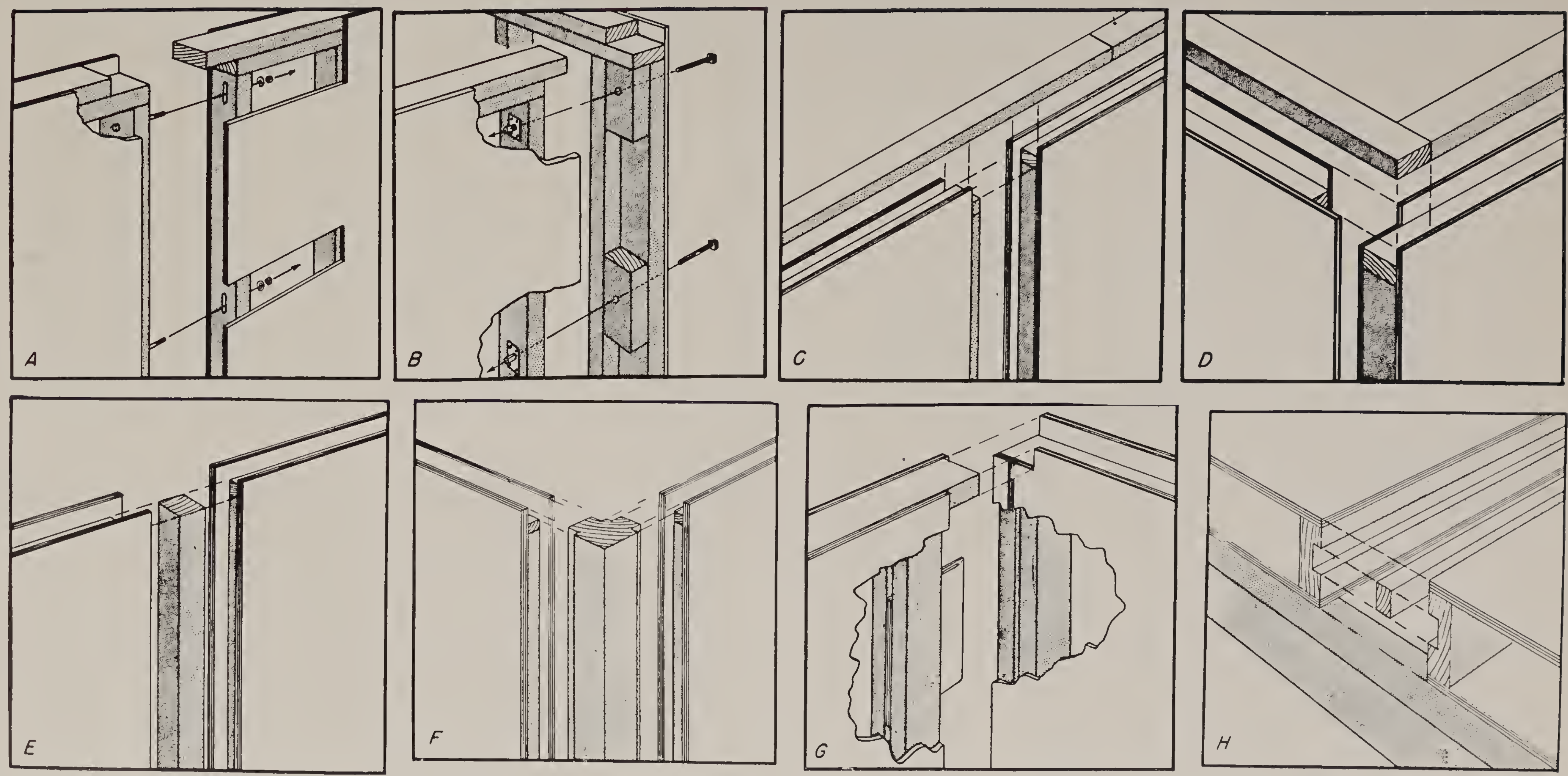


FIGURE 14–23.—Various methods of joining panels. *A* and *B*, bolted joints between panels and at corners; *C*, joint between panels utilizing male and female studs; *D*, corner joint with cover of one panel overlapping edge of other; *E*, mullion joint; *F*, corner joint with mullion; *G*, joint consisting of plywood tongue fitted into groove between a pair of studs of opposite panel; *H*, spline joint in floor panels.

strength or durability of the structure, but because it has been a matter of such widespread concern among prefabricators from the standpoint of consumer preferences.

Exterior joints can, of course, be entirely concealed by attaching siding or some other coverage to the plywood at the site. Many prefabricators have taken this course, particularly when employing some traditional design of house that calls for such exterior treatment. Such treatment, of course, increases building costs. Others emphasize the joints with covering strips, achieving not unpleasant effects. One common practice with houses of modern design, however, is to bevel the edges of abutting panels, which results in a V-joint. Interior joints may be similarly treated or covered with either wallpaper or accenting moldings or insert strips.

The problem of seam treatment at joints is, of course, eliminated when room-size sheets of wallboard are used (fig. 14–22) and rooms are so laid out that joints between sections of walls are concealed by intersecting partitions. Conventional moldings are then used to cover corner joints at walls, ceilings, and partitions.

Aside from its esthetic aspects, however, the problem of panel joints is principally to obtain an effective linkage of the component parts of the walls, partitions, floor, ceiling, and roof. Various methods employed by prefabricators to join their house panels are shown in figure 14–23.

The joints shown in figure 14–23, *A* and *B*, are commonly used to join the units of partially preassembled houses shipped to the building site in units consisting of walls, floors, and ceilings. It is usually necessary to allow cutouts in the wall coverage so that bolts can be inserted and tightened; cover plates are then inserted to cover the hole. It is often possible to conceal such cutouts with moldings, wallpaper, or by installing closets or other units at the joints where they occur. Bolted joints are often used for demountable housing. Common bolts are usually used for bolted joints.

The most common joint used in stressed-cover construction is that shown in figure 14–23, *C* and *D*. The male and female studs of this joint, together with the plywood cover, constitute a tongued-and-grooved joint. This joint is usually nailed. The male stud is often beveled to permit easier fitting during site assembly.

The mullion joint shown in figure 14–23, *E*, also constitutes, in effect, a tongued-and-grooved joint. It is, in fact, the prototype of the joint shown in figure 14–23, *C* and *D*. It serves as a spacer between panels, and is usually nailed in place between edges of panel covering material. It also acts as a load-bearing member, but ordinarily the stressed-cover panels have adequate strength.

Figure 14–23, *F*, shows a mullion-type corner joint used with stressed-cover panel construction. The mullion is made by simply gluing two members as wide as the panel studs but only one-half as thick to two adjoining faces of a nominal 4- by 4-inch member. Thus a mullion is produced with two tongues that fit into grooves of adjoining panels. The advantage of this mullion is that it permits a flush exterior joint between panel and mullion that does not require corner cover boards. This joint can be beveled or otherwise treated to harmonize with exterior joints between other panels. A slight gap between the inner covers of adjoining panels can easily be concealed with molding.

The plywood tongue joint shown in figure 14–23, *G*, while appearing somewhat more complex in design than joints *C* and *D* of figure 14–23, embodies the same tongue-and-groove principle. Plywood of the same thickness and construction as is used for the tongue is also used as spacing material between studs of the grooved member, thus the thickness of the groove corresponds with that of the tongue. The tongue is beveled to assure easy assembly of panels. This joint is adaptable for in-line, corner, and partition joining.

The spline joint shown in figure 14–23, *H*, may be used to connect floor, ceiling, or roof panels as a load-transferring member. It is seated in grooves cut into the outer joists of panels. A wide, shallow groove in the joists is preferable to a narrow one, extending farther into the joist, since the spline is in effect a miniature joist and is proportionately stiffer as its vertical dimension is increased. Usually the spline is fitted in place without glue. Assembly is facilitated by nailing the spline into one groove and then fitting the adjoining panel to it.

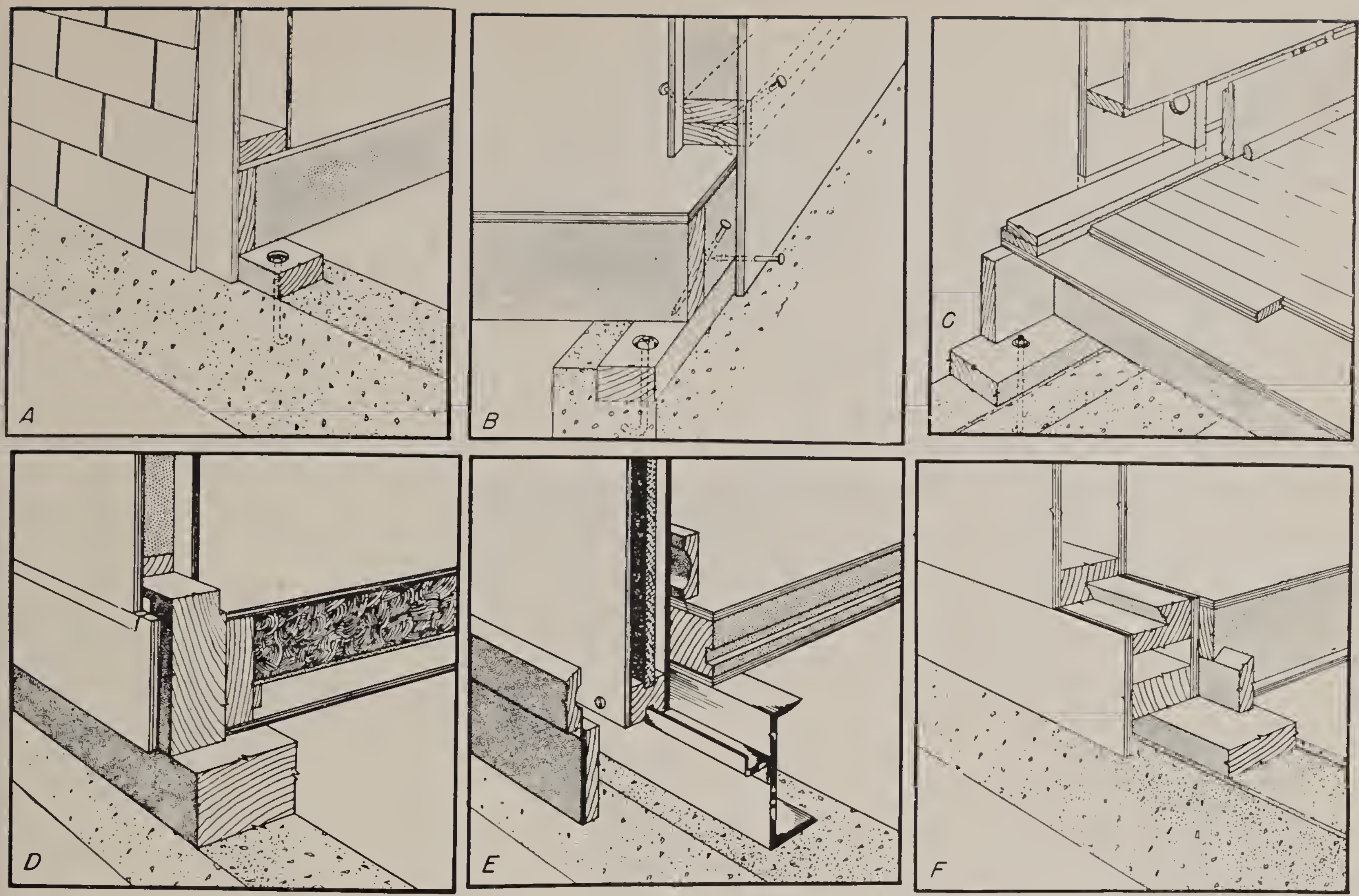


FIGURE 14–24.—Various methods of joining superstructure to foundation. *A*, desirable method of connecting nailed wall panels to floor and foundation; *B*, recessed foundation sill with wall panel overlap; *C*, sill plate bolted to foundation, conventional joist and floor construction, and prefabricated wall panel with base opening for electric wiring; *D*, method of connecting stressed-cover wall and floor panels to foundation by means of vertical sill bearing on sill plate; *E*, floor and wall panels clipped to foundation by means of channel fitted with flange for wall support; *F*, machined hook joint in wood members used to connect floor and wall panels to foundation.

14.171. Joints Between Foundation, Floor, and Walls.—The objective of joints between foundation, floor members, and walls is to anchor the entire building. The need for secure anchorage varies with different areas; but even in areas where high winds occur only occasionally, a firm anchorage is essential.

Prefabricators shipping to various parts of the country generally find it expedient to design foundation joints for the most rigorous requirements within their area, on the ground that local building codes do not always conform to local weather conditions with respect to foundation anchorage requirements.

Figure 14–24 shows several methods of anchoring superstructures to the foundation. General practice is to join the walls to the floor and the floor in turn to the foundation sill, which should be fastened to the foundation.

Figure 14–24, *A*, shows a method of joining walls and floors to foundations that is typical of some prefabricated construction. The outer covering of the wall panel overlaps the floor header and foundation sill and is nailed to both to obtain good anchorage. The sill is anchored to bolts set in the foundation when the concrete was poured. Five-eighths-inch bolts 6 feet apart, sunk 2 feet in the concrete, are usually recommended for anchorage in areas subject to wind damage. A somewhat similar method of joining is shown in figure 14–24, *B*, the principal difference being that the foundation sill is set into the foundation. The practice of setting wood into concrete as shown usually accentuates the likelihood of decay attacking the sill, because moisture may be trapped between concrete and wood (ch. 6).

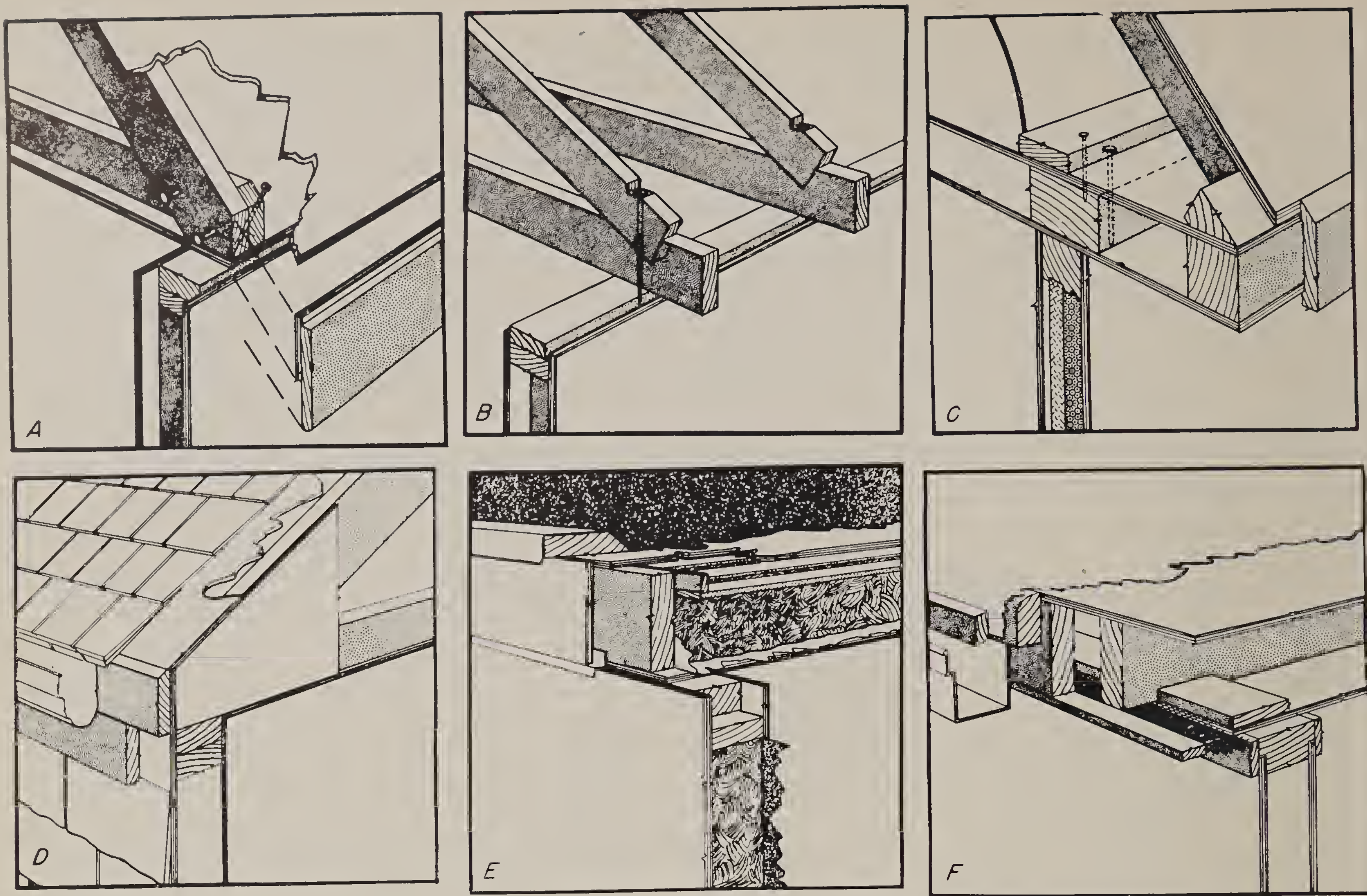


FIGURE 14–25.—Various methods of joining roofs to walls. *A*, pitched roof rafter fastened to ceiling joist and joist to top plate of wall panel; *B*, pitched rafter seated in joist and assembly fastened with a single lag screw to panel plate; *C*, block joint with lateral thrust exerted against block attached to second-floor panel, which is in turn fastened to top wall plate; *D*, truss-type roof; rafter or upper chord firmly held to joist or lower chord of truss with nail-glued gusset plates and truss fastened to wall plate. *E* and *F*, flat roofs consisting of stressed-cover panels which act as box beams.

Also conventional in most respects is the method of joining shown in figure 14–24, *C*. The wall panel in this design provides for convenient site installation of electrical wiring by means of a continuous opening at the base of the panels that is later closed with a fitted baseboard.

The method of anchoring shown in figure 14–24, *D*, was devised for use in connecting prefabricated wall and floor panels of stressed-cover construction to foundations. Its principal feature is a continuous vertical sill to which wall panels are attached and which in turn is bolted to the horizontal sill. The top edge of the vertical sill is shaped to fit between the covers of the wall panel.

The steel channel equipped with a metal flange to support wall panels, as shown in figure 14–24, *E*, provides a uniform base for floor and wall panels despite occasional irregularities in the surface of the concrete foundation wall. This level base facilitates assembly of house panels and other parts. In addition to the support afforded wall panels by the flange, they are bolted horizontally to the channel. The lower flange of the channel is held to the foundation by means of metal clips bolted to the foundation. The use of such steel members, particularly with basementless houses and where insulation is not provided, is doubtful from the standpoint of heating efficiency.

Figure 14–24, *F*, shows a joining method consisting of machined wood parts that interlock between wall and floor panels. In the system employing this design it is also utilized for locking wall, floor, and ceiling panels together and to join walls, ceiling, and roof. It requires

careful machining, as do all such joints between wood members, and use of well-seasoned lumber to avoid subsequent distortion that may reduce its effectiveness. Use of such machined joints where strength is dependent upon good glue bond, as between wall panels, is subject to the limitations discussed in section 13.21.

14.172. **Joints Between Roofs and Walls.** — The functions of the joints between walls and roofs are (1) to resist both lateral and lifting forces, such as those exerted by high winds and (2) to resist outward thrust. In the conventional pitched roof framed with rafters and joists, these functions are met by fastening the roof rafters to the ceiling joists and the joists in turn to the top wall plates. This joint creates in effect a truss, transmitting roof loads to the walls.

Figure 14–25, *A*, shows such a joint applied to a prefabricated house. In this case, the roof rafters are preassembled with plywood coverage in sections and nailed to the ceiling joists on the building site.

The joint detail shown in figure 14–25, *B*, connects roof and ceiling panels to the wall-panel plates with a single lag screw.

The block joint shown in figure 14–25, *C*, was designed to permit assembly of pitched roof panels to ceiling panels. As shown, it is used to join roof panels with a single plywood cover to panels that serve as a second floor in a house. The bearing block can be glued to the floor panels in the factory or spiked in place at the site. Its purpose is to transmit thrust loads to the ceiling panels, thereby minimizing outward thrust loads upon wall panels.

The prefabricated truss joint shown in figure 14–25, *D*, is probably the most effective device for transferring loads on pitched roofs to walls without exerting appreciable thrust upon the walls. The gusset joint between upper and lower chords is an excellent device for the transfer of load stresses from the rafter to the joist. A typical roof truss designed for prefabricated houses is shown in figure 14–12. The truss can be attached to the walls by toe nailing or by means of metal angles.

The joint shown in figure 14–25, *E*, was designed by the Forest Products Laboratory for a flat-roof house employing stressed-cover roof panels. A tongue member is glued to the under side of the panel at either end and is seated into a groove along the top of the wall panel. This tongue can then be fastened to the wall by nailing into it through the plywood wall covers. The amount of thrust action on the walls from roof loads depends upon the amount of deflection produced in the panels by the loads. If panels are designed for adequate stiffness, thrust action under load should be reduced to a negligible amount. The joint shown in figure 14–25, *F*, differs from joint *E* in that the roof panel lies flush on the top plate of the wall panel, being held in position by means of screws that are driven through a bearing plate incorporated in the roof panel into the top plate of the wall. This member is installed in the factory during fabrication of sectional house units. A continuous header is installed after the panels have been fastened.

14.173. **Protection of Exposed Joints.**—Faulty or insufficiently protected joints at eaves and foundations, around windows and doors, and at other exposed points in the house can cause serious difficulties if moisture is permitted to enter the structure through them. Horizontal seams are especially exposed to such hazards, since moisture, which may seep into them, is not easily drained away or evaporated.

The use of drip caps (fig. 14–26), metal flashing (fig. 14–27), and sloping window sills in window construction is widespread among builders. Such millwork is often purchased ready for installation with these factors provided for by the millwork manufacturer. They may, however, also require sealing with a putty or mastic around the perimeter to prevent possible heat leakage and to make the joint between window framing and rough opening watertight. Door framing requires similar protection.

Such critical points as the joints at the eaves and the foundations are usually protected with cover boards, flashing, molding, or water tables. The design of such details should always assure that water will run off rather than have opportunity to penetrate the seam.

14.18. **Tolerance.**—In the production of prefabricated house parts of wood and related wood-base materials, the factors that govern allowable tolerances include (1) the capability of machines to approach design dimensions under commercial operating conditions; (2) the properties of the materials being worked, most im-

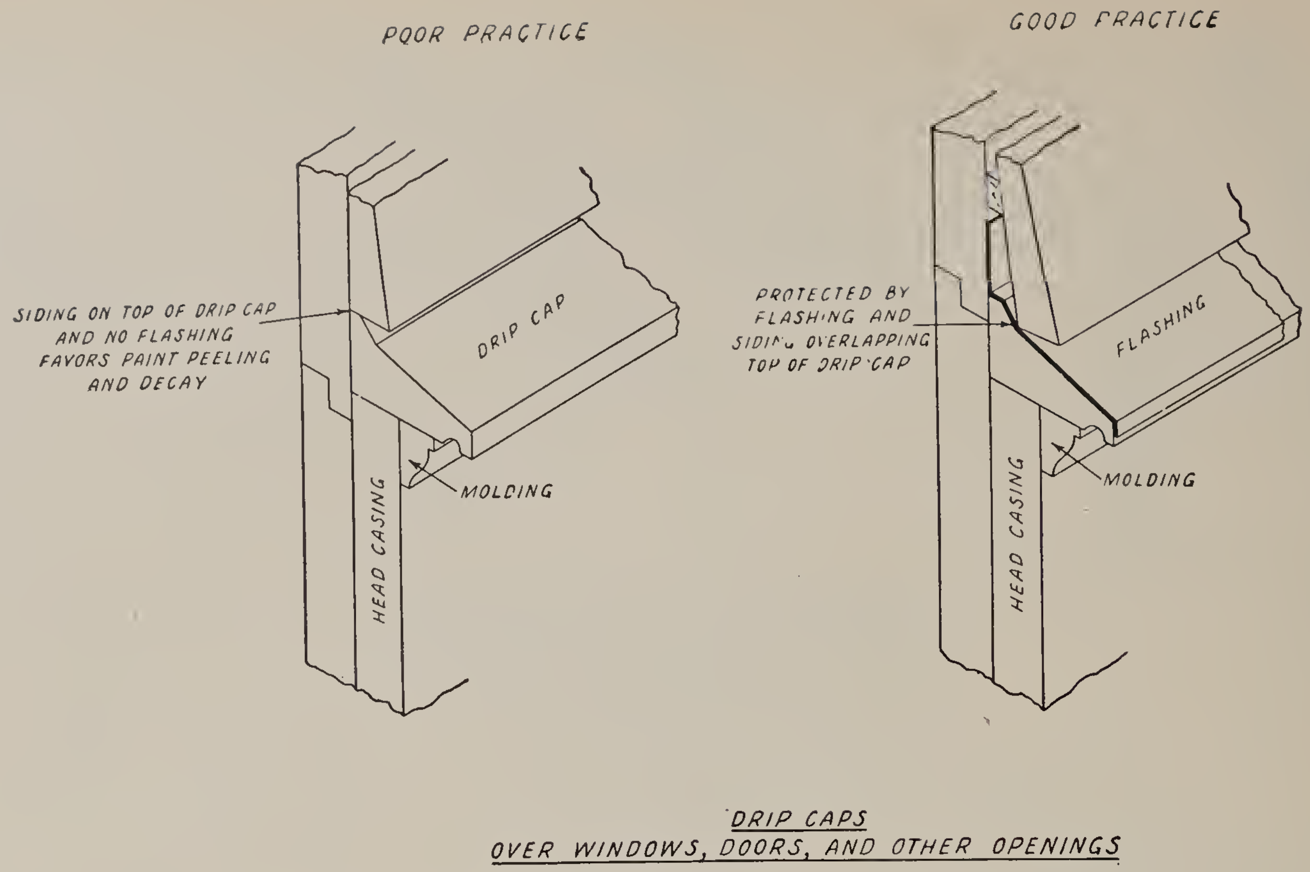


FIGURE 14–26.—Good and poor practice with drip caps.

portant of which with wood is its tendency to swell or shrink with changes in moisture content; and (3) the extent to which design dimensions can be exceeded on the plus or minus side without interfering with good fit of parts to be assembled.

Tolerance requirements vary somewhat with the type of house being produced. Nailed panelized construction done largely with hand tools is obviously less limited by tolerance requirements than is prefabrication of stressed-cover panels where effective glue joints, well-fitted panel joints, and other critical points are essential to good construction.

14.180. Machining Limitations.—The most critical operation affecting achievement of close tolerances is planing (sec. 10.10). While the available data on the subject vary somewhat, in general a high degree of precision can be obtained. One manufacturer reports that, under the best machining conditions and with exceptionally expert care, tolerances as close as 0.0005 inch, plus or minus, can be obtained. The same manufacturer reports that, under typical commercial conditions and with indifferent attention to machine adjustments and other factors, a tolerance of 0.005 inch should be achieved.

Experience demonstrates, therefore, that lumber can be planed and molded to any tolerances that are likely to be required in the manufacture of prefabricated house panels provided the machines are kept sharp and in proper adjustment, and other conditions are suitable.

Sawing, dadoing, and similar cutting operations usually do not permit working to such close tolerances as are possible in planing. With sawing, probably one thirty-second (0.031) inch is as close a tolerance as can be expected under normal factory operating conditions, although with such machines as the double-end tenoner this tolerance may be brought down to one sixty-fourth (0.0156) inch. Similarly, in the cutting of gains with a dado head, it is unlikely that tolerances can be brought lower than one sixty-fourth inch, with one thirty-second inch more common under shop conditions. Resawing, one of the most difficult of operations where great accuracy of cut is required, probably will limit tolerance to one-sixteenth (0.0625) or three thirty-seconds (0.094) inch. After resawing, of course, lumber may be planed to achieve closer tolerances.

Sanding normally is not usually regarded as an operation adaptable to attainment of close tolerances. Planing is generally more practical.

14.181. Materials Limitations.—The properties of materials that affect tolerance are (1) the

FIGURE 14–27.—Metallic flashing installed around a window before attachment of outer coverage.

physical properties that determine dimensional stability and (2) machining properties.

14.1810. Physical Properties.—The dimensional stability of wood, plywood, and other wood-base materials is dependent upon maintenance of the required degree of dryness (sec. 3.7). Wood is affected so little by even extreme changes in temperature that dimensional changes from this cause can be disregarded. Shrinkage and swelling with changing moisture content are the principal causes of difficulty in the assembling of wood parts and, therefore, markedly affect tolerance requirements. It is axiomatic that, where close tolerances are being used, wood must be kept dry. Even variations of a few percent in moisture content can cause difficulty.

The amount of shrinkage or swelling with changes in moisture content can be calculated from the formula:

$$S = \frac{dc}{\left(\frac{f}{r} - f\right) + m}$$

Where S is the change in dimension in inches, either shrinkage or swelling; d is the dimension of the wood in inches; c is the change in moisture content values within the limits of the oven-dry condition and the fiber-saturation point; r is the applicable percentage of shrinkage from the green to the oven-dry condition expressed as a decimal; f is the fiber-saturation point of wood, usually considered to be 30 percent; and m is the moisture content in percent when wood is at dimension d, but never to be taken greater than f.

Example: Assume a flat-grain Douglas-fir stud which has been planed at 15 percent moisture content to finished dimensions of 3 inches and subsequently dried to 6 percent moisture content in a warm, dry factory before being installed in a stressed-cover panel. Table 3–2 shows that the shrinkage in width (tangential) from 30 to 0 percent moisture content for Douglas-fir is 7.8 percent of the green dimension. The amount of shrinkage can be calculated with the formula above, as follows:

$$S = \frac{3\ (15 - 6)}{\left(\frac{30}{0.078} - 30\right) + 15}$$

$$S = \frac{27}{(384.6 - 30) + 15} = \frac{27}{369.6} = 0.073 \text{ inch}$$

The change in dimension, since the moisture content is lowered, represents shrinkage. The shrinkage in the 3-inch flat-grain member would therefore amount to 0.073 inch, an amount greatly offsetting the close tolerance to which the member was planed when air-dry. In fact, a variation of as little as 2 percent in moisture content would be sufficient to offset a 0.015-inch tolerance.

This example emphasizes the need of protecting well-machined stock from serious change in moisture content from the time it is machined until it is installed in the panel. The most certain means of controlling dimensional change, therefore, is to arrange a production schedule whereby closely machined parts are installed directly from the machining operations without an intervening period of storage under conditions favoring a change in moisture content (ch. 9).

Since plywood does not shrink or swell nearly so much as does normal wood except in the thickness direction (sec. 3.71) dimensional changes due to this cause are less important from the standpoint of tolerance. Plywood must, however, be stored under conditions that will avoid serious change in moisture content and consequent swelling or shrink-

ing in the thickness direction. Swelling is generally the hazard to be guarded against, because of the low moisture content at which most plywood is manufactured. Sanded Douglas-fir plywood conforming to commercial standards of manufacture (sec. 4.1) is manufactured to a thickness tolerance of one sixty-fourth inch, sufficient to avoid any serious difference in thickness of adjoining sheets in house panels; unsanded Douglas-fir plywood is manufactured to a tolerance of one thirty-second inch. Subsequent changes in moisture content during storage can, however, result in swelling of edges and end checking that upset required tolerances.

Fiberboards, both structural wallboards and insulating boards of the rigid type, are also subject to dimensional change with absorption of moisture. The various commercial board materials vary considerably, however, and the prefabricator concerned with tolerances applicable to these materials should obtain data on the effects of water absorption upon linear expansion from the manufacturer of the brand he is using. Federal Specification LLL-F321b for class A insulating fiberboards limits linear expansion of material one-half inch thick to 0.5 percent and water absorption to 7.0 percent under prescribed exposure tests. Federal Specification LLL-F311 for hard-pressed structural wallboard 0.125 inch thick (tolerance 0.0156 inch) limits water absorption to 20 percent under a somewhat different exposure test than that for insulating boards.

14.1811. Machining Properties.—The effects of wood properties upon its machinability are discussed in section 10.1. Machinability of wood is affected by its physical structure, specific gravity, tendency to warp, and other physical properties, including moisture content at the time of machining. In general, however, the common structural woods used in manufacture of prefabricated houses are relatively easy to machine, and comparatively little difficulty should be experienced with any of them in attaining desired tolerances.

14.182. Tolerances for Stressed-cover Design.—In arriving at suitable design tolerances for stressed-cover construction, the designer must determine first of all the critical elements of the construction that will be affected by dimensional variations. There is little point in setting close tolerances for parts where accuracy of dimensions is unimportant.

Among elements that obviously require close machining tolerance are all grooved joints, such as spline and mullion joints, that affect ease of assembly in the plant and at the building site; the width of frame members, which governs panel thickness and proper mating of gluing surfaces at joints between members; the length of framing members, which affects jig assembly; and the overall width of finished panels, which controls the amount of "gain' or "growth" of walls when assembled on the foundation.

On the other hand, there is no particular point in planing framing members to close tolerance in the thickness direction. In fact, resawing is probably accurate enough to cut thick stock to stud size, without any planing.

The first step in setting tolerances, then, is to analyze each machining operation to determine how it is affected by the need for close tolerances in the assembly and ultimate functioning of the finished structure. Once this has been established, the problem of deciding upon the tolerances needed in the design of the parts becomes simplified.

14.1820. Glue-joint Tolerances. — All tolerances affecting glue joints must be as close as machining operations will permit, since it is essential that intimate contact be established between mating surfaces if a strong glue bond is to result (sec. 11.31). This is particularly true of joints between framing members and covers of stressed-cover panels, because concentration of stresses will occur at gaps in the glue joint (sec. 14.1111). The gluing surfaces of framing members should be planed to a tolerance of at least one sixty-fourth (0.0156) inch to assure uniformity of width and smooth joining of surfaces where framing members meet. At least the same tolerance is necessary for scarf joints in plywood.

14.1821. Panel-joint Tolerances.—In most cases, the tolerance for joints between wall panels will be established by the tolerance set for the framing members. If the framework has been machined to a tolerance of one sixty-fourth inch, this will automatically establish the tolerance in the groove formed by the plywood cover extensions. The mating stud, to assure a good fit, should be slightly tapered so that it

FIGURE 14–28.—Tolerance gap provided between roof panels to permit installation of a filler strip of width necessary to make up normal losses or gains in site assembly.

will slip readily into the adjoining panel groove; an allowance of one thirty-second inch is recommendable for this taper, or bevel. Some manufacturers also bevel the projecting edges of the plywood to avoid mashing of fibers and permit easier fitting of the stud in the groove.

Spline joints require separate machining operations for the grooves in adjoining framing members and the splines that will be fitted into them. This is perhaps a more critical joint than the tongued-and-grooved joint, especially if it is to be glued. Not only must the spline fit properly in the groove, but it must meet the requirements of good gluing to avoid both excessive glue squeeze-out that may cause a starved joint and lack of squeeze-out resulting in a dried joint. It is recommended that, where glued spline joints are used, machining tests be run to determine the degree of accuracy essential. Usually, however, spline joints are not glued, and the splines and grooves may be beveled to permit easier assembly.

14.1822. Width Tolerance for Panel.—The need for close tolerances governing the width of prefabricated panels arises primarily from the fact that, during site assembly, walls, floors, ceilings, and roofs must remain within the prescribed over-all dimensions of the building. It is more important that these dimensions not be exceeded than that the assembled wall fail quite to meet them. Consequently, builders work to the design dimension as a maximum, setting tolerances on a minus basis. That is, actual width of the panels can be, say, one thirty-second inch short of design width but it must not exceed that width. The longer the panels, of course, the greater the allowable tolerance on the minus side, provided that the total loss for a wall does not exceed that which can be provided for at the corners of the building or at some other point, such as the joint between certain panels.

Corner joints are usually designed to absorb differences from design dimensions. Thus, the

FIGURE 14–29.—Steel-top jig fitted with removable steel angles for alinement of framing members of a stressed-cover panel.

joint shown in figure 14–25, *F*, can be assembled readily even though the total loss in the wall from design dimensions equal one-fourth inch or more. A panel for a doorway may be utilized to take up such losses because the door trim can be used to cover resulting gaps. A method of adjusting for gain in roof panels is shown in figure 14–28; a tolerance gap is provided between specially designed panels that is wide enough to permit installation of a plywood strip cut on the job to the exact width necessary to make up normal losses or gains. Roofing conceals this filler strip. Floor panels can sometimes be similarly designed.

The determining factor in providing for tolerance in panels of tongue-and-grooved joint design is the width to which the plywood cover is trimmed in the equalizer (fig. 10–9). A desirable tolerance for such trimming is one sixty-fourth inch plus or minus, with the machine adjusted to trim the sheets one sixty-fourth inch under the design dimension so that it not be exceeded in any case. Such a setting, of course, will result in variations of as much as one thirty-second inch less than the design dimension. Even a loss of one thirty-second inch in width for each of eight 4-foot panels in a 32-foot wall would, however, total only one-fourth inch, an amount easily taken care of at the corner joints. Imperfect mating of panel joints would not be expected to aggregate more than one-fourth inch, making the total loss not more than one-half inch.

For panels that are spline-joined, sizing is usually done with a double-end tenoner (fig. 10–8). The precision of such a machine permits attainment of accuracies comparable with those possible on an equalizer, and the same toler-

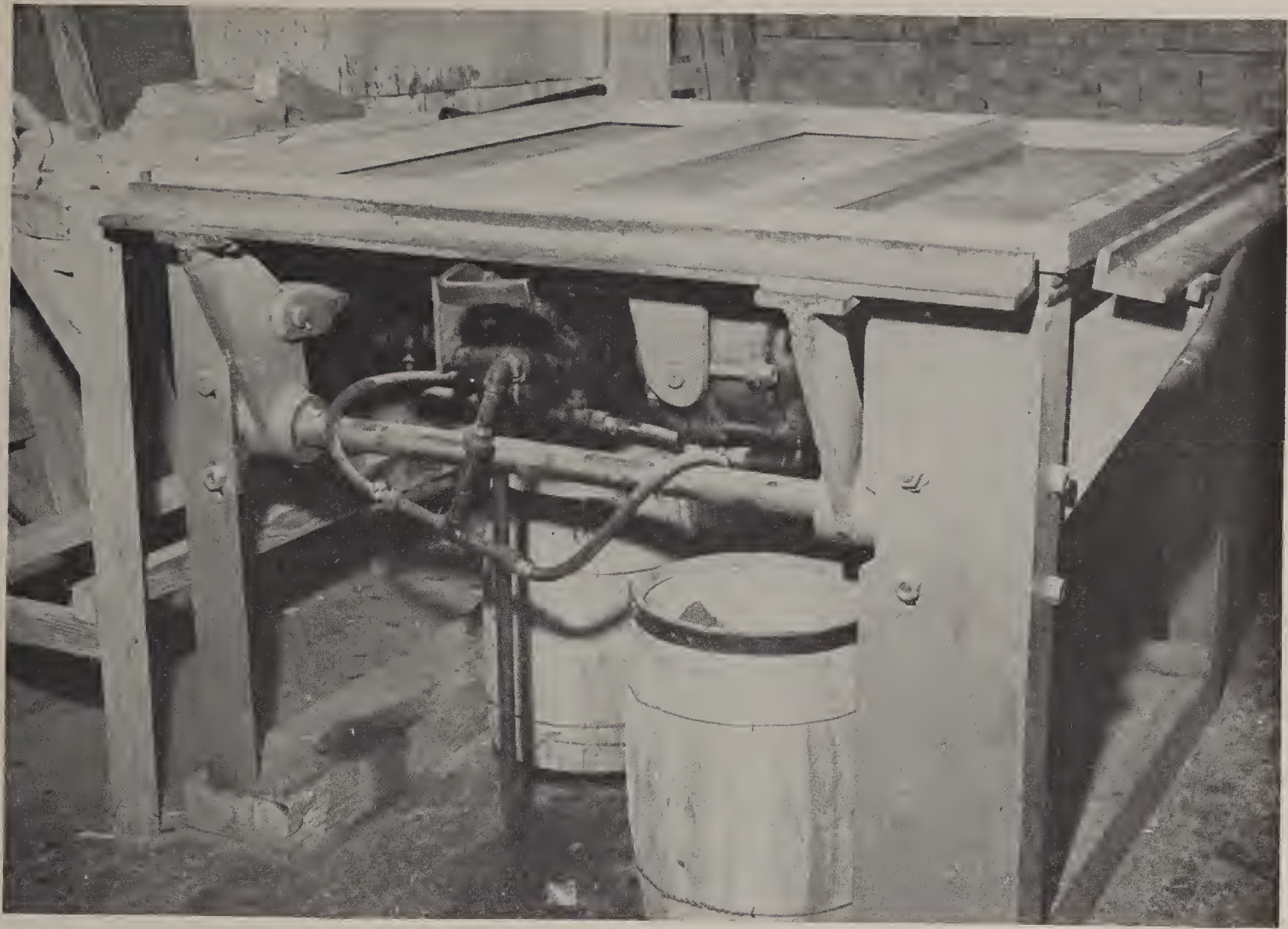


FIGURE 14–30.—Pneumatically operated clamp jig. Angle bars at sides of top are driven home against outer framing members by means of air-driven rods attached to rocker arms.

ances can be worked to. A tolerance of one thirty-second or one sixty-fourth inch is recommended.

14.2. PRODUCTION METHODS AND EQUIPMENT.

14.20. General.—Whatever the product, a basic principle of its manufacture is to utilize the methods and machines most suited to the materials and parts to be made. Production methods and equipment thus become as much an engineering problem as does the design of the product, whether it be a prefabricated house, an automobile, or an adding machine.

This discussion is limited to a review of production methods and equipment in use at house prefabrication plants in various parts of the United States. The methods and machines mentioned here may not always be the best for the particular tasks involved, either from the standpoint of production economy or that of quality of the final product. Individual producers are confronted by many problems, not the least of which is the newness of the house prefabrication industry as a whole, and the resultant lack of experience with existing methods and machines. New and more efficient processes and equipment will undoubtedly be forthcoming rapidly as engineering skills are developed and applied to the intricate problems of prefabrication.

House prefabrication in the United States today ranges from the small shop equipped with a few simple machines and jigs and largely dependent upon handicraft methods, to large plants operating with full-scale line production systems. The industry is fortunate, however, in that its very lateness in arriving upon the industrial scene places at its disposal a great body of production experience gained in other lines of manufacture *(14–1, 14–2, 14–7)*.

14.21. Storage of Materials.—Volume production of houses requires extensive storage facilities for lumber, plywood, wallboard, in-

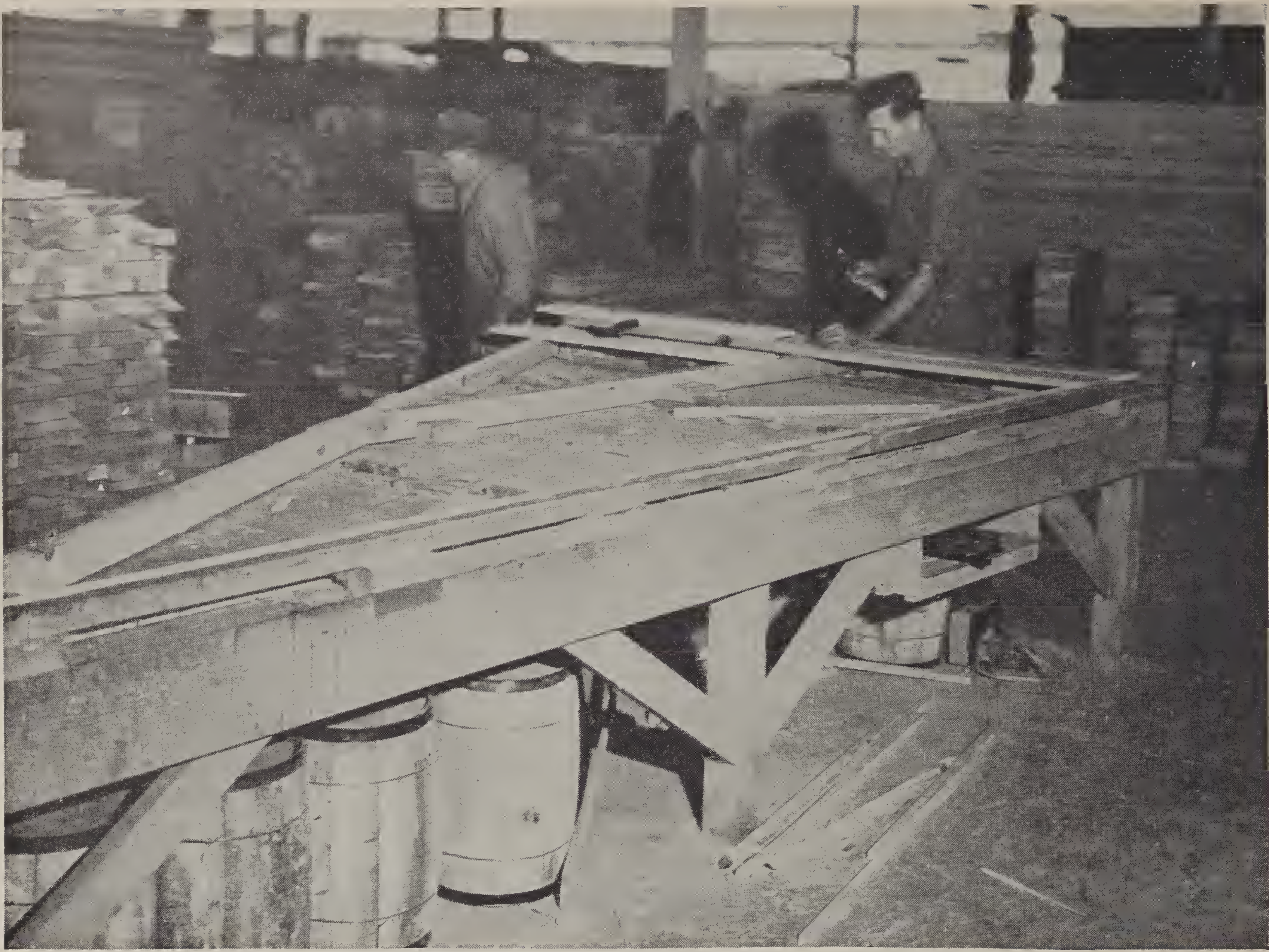


FIGURE 14–31.—Jig for assembling gable half-section.

sulation, and other materials. Even a small prefabricator producing one or two houses a day requires considerable yard and warehouse space. Recommended conditions of storage are discussed in chapter 9.

Because of differences in piling and other practices, it is not possible to give close estimates of storage space required for a given volume of material. The forward-looking prefabricator will plan his yard and factory setup to allow adequate space for handling of materials as well as for future expansion of operations.

14.22. Plant Equipment.—The equipment of the prefabricating plant may range, depending upon size and volume of output, from a few simple jigs, hand trucks, and dollies to highly integrated conveyor systems.

14.220. Jigs.—Jigs are used in all prefabricating plants to insure accurate assembly of parts. The jig governs the dimensions of the finished part to a degree of precision depending somewhat upon its construction.

A rather accurate type of jig used for assembly of framing components of stressed-cover panels is illustrated in figure 14–29. This jig has a steel top and supports precisely machined to insure its flatness. Removable steel positioning angles permit adjustment for various sizes and types of panels by means of bolts inserted through accurately alined holes in the steel top. True alinement of the bolt holes is essential for precision assembly of framing panels.

A jig with a pneumatically operated clamping device is shown in figure 14–30. Framing members are laid in position on the steel top of this jig, and are then clamped rigidly in position by means of angle bars around the perimeter of the panel, which are pneumatically operated. This device permits rapid assembly

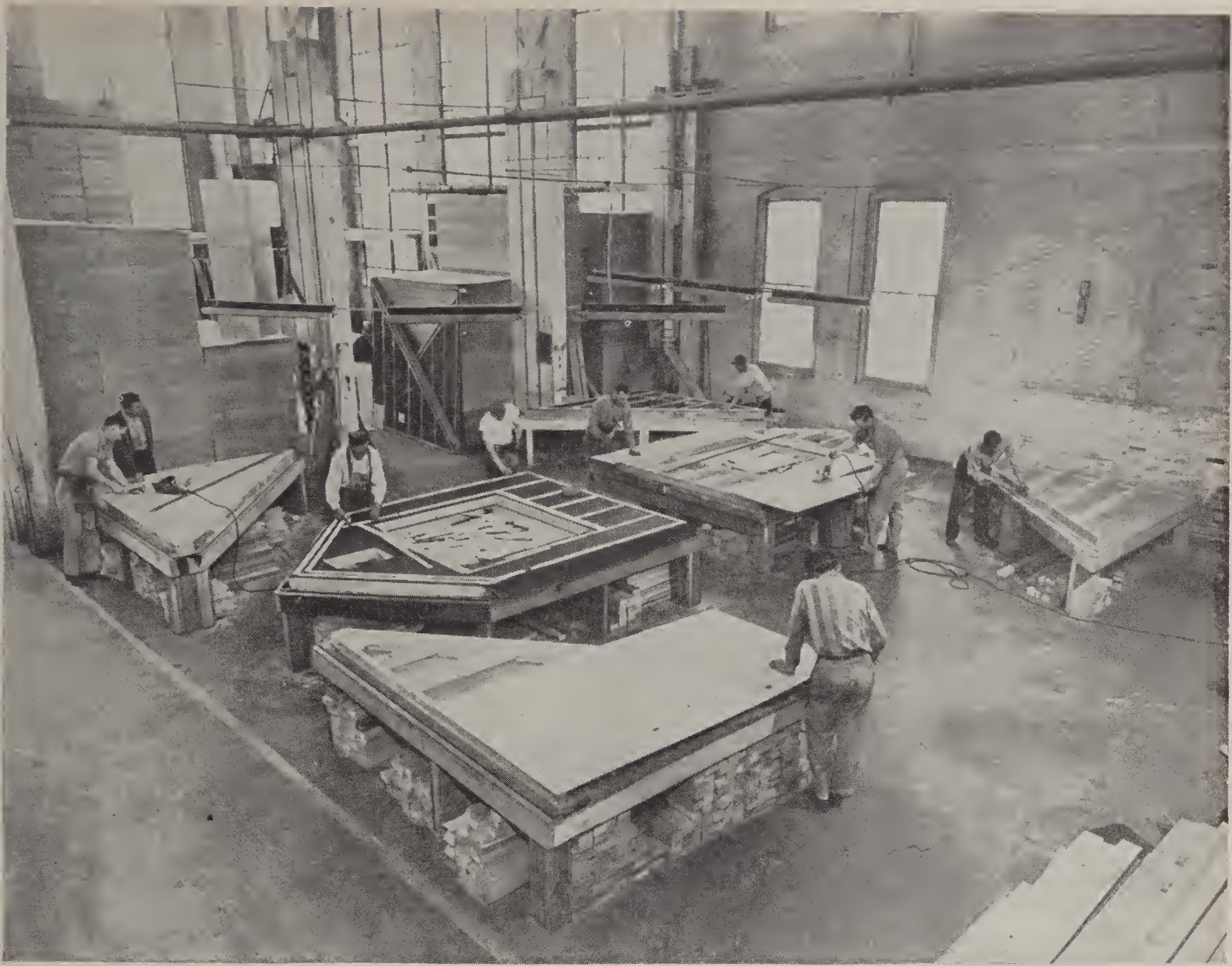


FIGURE 14–32.—Setup of six jigs used to assemble both gables of a house. Each gable is in three sections, the center one containing the peak and a window, the two triangular sections being attached to either side of it at the site.

of simple panel components, which can then be fastened together by means of corrugated fasteners or staples.

Many prefabricators make jigs with wood or plywood tops, planing them to the required degree of flatness. First cost of such jigs is low as compared with a machined steel jig. They should be inspected at intervals and resanded as necessary to maintain flatness of the top and accurate alinement of the blocking or other positioning devices. A useful device for applying pressure to framing members in order to fit them tightly together is a simple eccentric operated by means of a hand lever on the cam principle when bolted in position on wood jigs. Another means of applying pressure is a wedge of specified taper inserted between the framing member and the block. Metal wedges and blocks are preferred, to avoid distortion through repeated use and consequent loss of accuracy.

Figure 14–31 shows a simple jig devised for assembly of a gable half-section. Positioning of gable framing is governed by wood blocks spiked to the jig top. These guide blocks should be somewhat lower than the framing members so that coverage can be attached on the same jig. Such jigs are used in pairs, since both half-sections cannot be assembled on the same jig.

A conveniently arranged setup of jigs for production of gable-end sections of a prefabricated house is shown in figure 14–32. Six jigs are used to produce both gables of a simple pitched-roof house simultaneously, each gable end being assembled in three sections.

Where production volume warrants, jigs can

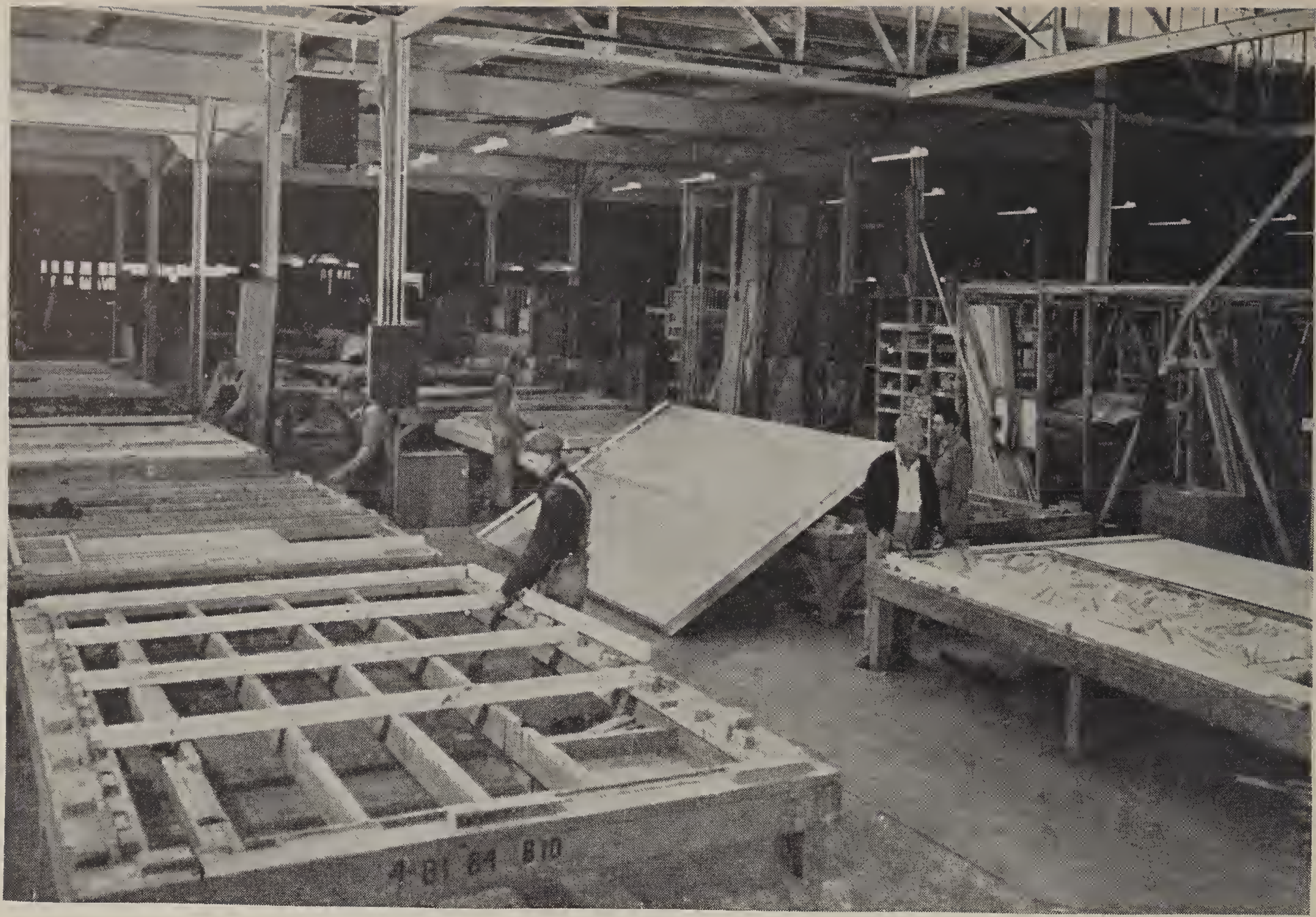


FIGURE 14–33.—In-line jig setup. Left, framing jigs; right, tables for attachment of covers and insulation.

be set up for mass production of parts (fig. 14–33). Framework is assembled on one line and the frames are then moved to another line where one cover is attached, insulation inserted, and the second cover put in place.

An unusual type of portable jig mounted on trucks is shown in figure 14–34. This jig is used to position plywood covers on a framework after the frame has been passed through a glue spreader. After the cover is lightly tacked in place, jig and panel are pushed to a hot press, the clamps released, and the jig swung to a horizontal position at press level. Both covers can be attached simultaneously with this jig.

14.221. Conveyor Systems.—As used in prefabricating plants, conveyor systems are of various types: (1) lines of what are essentially stationary jigs, assembly tables, and horizontal roller-top stands; (2) overhead tracks to which panels and other parts are hooked and moved by manual power; and (3) continuous moving belt or chain conveyor systems, either vertical or horizontal.

Handling of frameworks and panels in various stages of completion is chiefly by manual power with the first type of conveyor system. Figure 14–35 illustrates a simple and flexible adaptation of the roller type of horizontal conveyor. Individual stands with rollers can be spaced and moved about conveniently to suit the type of panel or other part being assembled. They provide a base solid enough for attachment of covers to light panel constructions, and sometimes are used also for installation of insulation. For convenience, one edge of a panel can rest on the floor (fig. 14–36) while workmen perform various tasks. Light panels are easily pushed from station to station.

Overhead conveyor systems are especially useful for painting and other finish work on panels, such as installation of windows and trim (fig. 14–37). They are also used to move frameworks of panels from assembly jigs to glue spreaders or to assembly tables where insulation and outer covers are applied, as well as through spray booths and paint-drying chambers. Figure 14–38 shows a method of

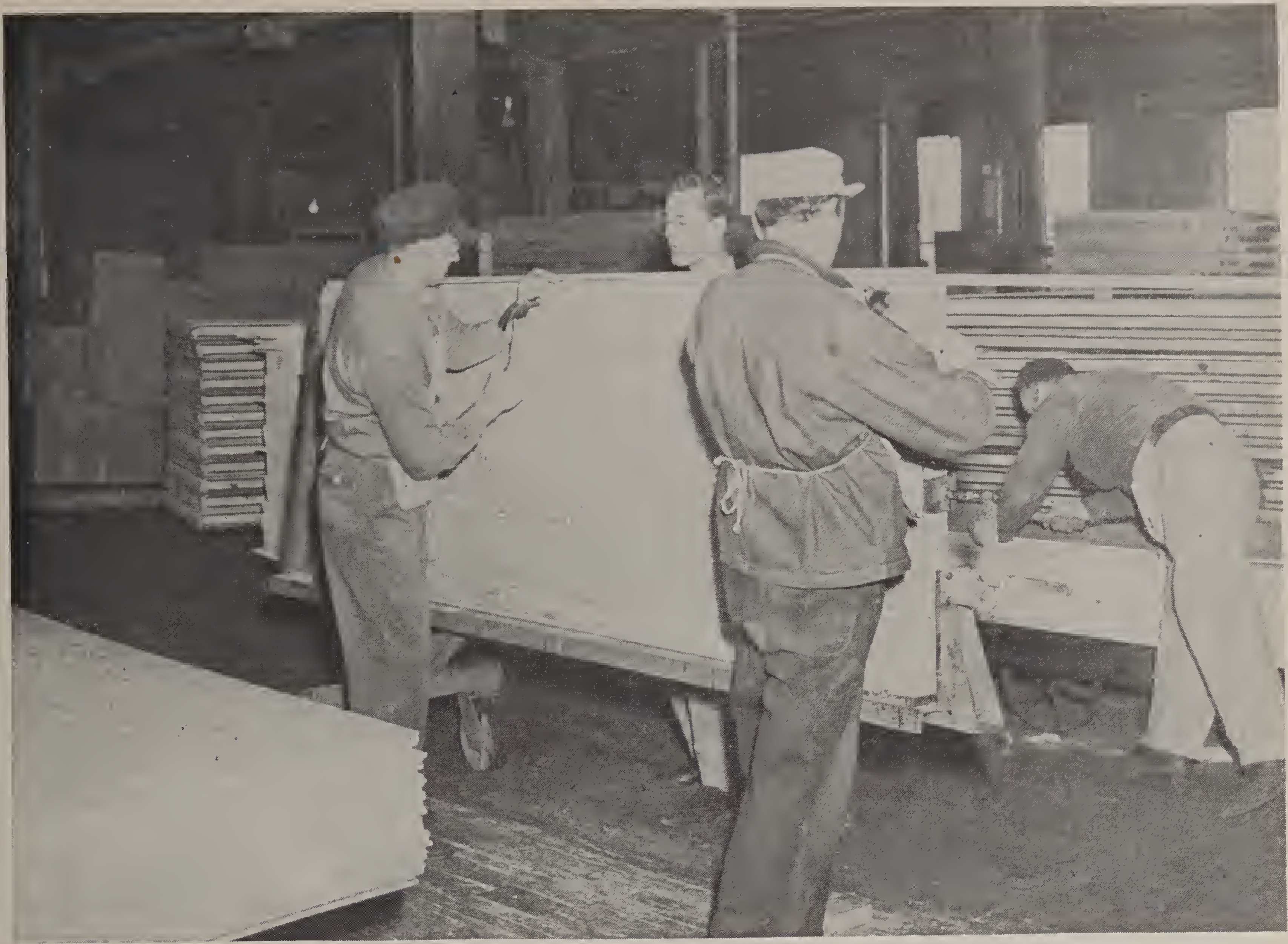


FIGURE 14-34.—Portable jig mounted on trucks for use in moving panel to hot press after cover has been tacked to framework.

moving millwork through a painting booth with special racks hooked to overhead tracks.

Conveyor systems that move at a continuous speed through various operations have as yet found but limited use in prefabrication plants. Speeds are slow, seldom exceeding a few inches per minute. Slow speed is necessary both to give workmen time to apply glue, nails, insulation, covers, and other materials to the panels and, where the line leads through spray booths, sufficient time to permit finish to reach a state of dryness permitting further handling of the panels. Even at such low speeds, it is necessary to use heat to speed paint drying, either with drying lamps or warm air. For some operations, the line can be stopped.

The vertical conveyor system shown in figure 14-39 is used for all operations after the assembly of the framework on jigs, including spray applications of a primer coat of paint. At several stations along such a line it is necessary to provide platforms or floor recesses so that workmen can conveniently perform operations along the top or bottom parts of the panel. Work can be done simultaneously on both panel faces with this type of conveyor.

In figure 14-40 is shown a horizontal type of continuous moving chain conveyor system. Whereas, with such a system, workmen can most conveniently work along the edges of the panels, it is in some respects not so convenient as the vertical system shown in figure 14-39. The difficulty of reaching points along the central portion of the panel cannot be overcome as it can with platforms and recessed floors at stations along the line of the vertical conveyor. Moreover, the panel must be turned over to attach covering to the other face. It does, however, facilitate assembly of framework along the line.

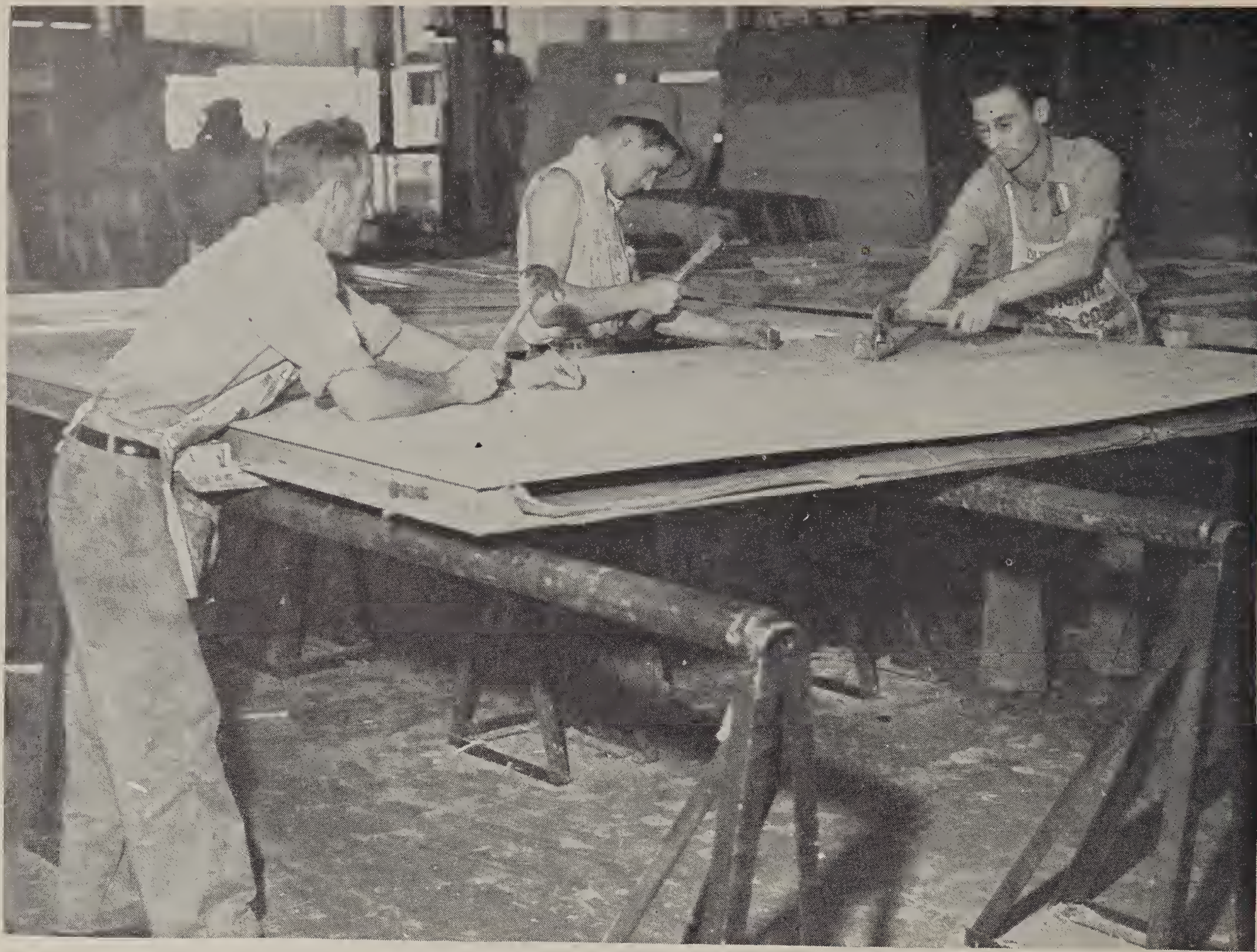


FIGURE 14–35.—Roller-top metal stands used for assembly of panels in line production.

An endless-belt type of conveyor is shown in figure 14–41. This conveyor is used to carry panels from assembly tables, where covers are attached, to high-frequency dielectric presses, and from the presses to a stacking point where they can be picked up by a fork-lift truck for removal to the warehouse.

14.222. Woodworking Equipment.—Various types of woodworking machinery used in prefabricating plants are described in chapter 10.

14.223. Gluing Equipment.—As with other equipment, the types of gluing devices employed depend primarily upon the type of house being built. Some prefabricators — notably those building nailed-panel houses—use little or no glue. Usually, however, the advantages of gluing for rapid assembly of parts, especially of covers to studding, are recognized in the prefabricating plant.

Most common means of applying glue is the glue gun shown in figure 14–42. This device consists principally of a long cylindrical container for glue and a spreading wheel which resembles a gear with shallow teeth. If correctly operated, it spreads glue satisfactorily where a long, narrow glue joint is required, as on the edges of framing members. Care should be taken in operating it to keep the spreading wheel as truly vertical as possible to the surface being spread; if the wheel is tilted, a narrow, inadequate line of glue is applied that will result in a starved joint (sec. 11.51). The glue gun operates on the gravity principle with liquid glues.

Other means of applying glue are by brush and by glue spreaders of the type shown in figure 11–9.

Other than equipment for application, the principal types of gluing equipment are pres-

FIGURE 14-36.—One edge of a panel is lowered to the floor while the other is supported on a roller-top stand for convenience in installing insulation in a panel.

FIGURE 14-37.—Overhead conveyor system in use for applying finish and window and door trim to panels.

FIGURE 14–38.—Special racks on conveyor system used to move millwork through a spray booth for painting.

sure devices and mixers. A variety of tools and machines used to apply pressure to glue joints while the adhesive is setting is shown in figures 11–5, 11–6, and 11–12. Mixing equipment suitable for preparing small amounts of glue is shown in figure 11–4. Larger mixing machines are available on the market. It is important, in planning glue-mixing operations and equipment, to keep in mind the working life of the glues used. Some glues, including the resorcinols, are coming into wide use for housing because of their exceptional durability among glues that set at room temperatures. They have a comparatively short working life (sec. 11.33), and to mix more glue than can be used within its working life results in waste.

14.224. Miscellaneous Equipment. — Prefabricating plants require a variety of tools and machines to handle materials and parts. Among these are various kinds of push trucks, hoisting devices, and motorized hauling and lifting machines, such as fork-lift trucks.

Figure 14–43 shows an adaptation of hand-truck equipment for moving of large partition sections containing kitchen cabinets, bedroom closets, and miscellaneous built-in furniture.

Figure 14–44 shows a large fork-lift truck used to load panels for transportation to the building site. Such trucks come in various sizes, some of them suitable for use inside the factory in such tasks as moving finished panels from the assembly lines to warehouse and loading platform. The lifting device is hydraulic and controlled easily by the driver.

Many auxiliary tasks can be simplified with equipment built in the shop. Figure 14–45 shows one such piece of equipment, a dip tank for treatment of lumber with antistain chemicals. The drainboard is fitted with sections of pipe on which boards can be piled after dipping to permit excess chemical to drain back into the tank. Figure 14–46 shows a similar treating tank into which lumber is lowered with a hoisting device.

14.3. SUBASSEMBLY OPERATIONS. — For the purposes of this manual, subassembly operations are considered to be those that prepare materials for and necessarily precede the final assembly of panels, trusses, box girders, and other sectionalized parts of prefabricated houses in the factory. Chief among these preliminary operations are grading, machining,

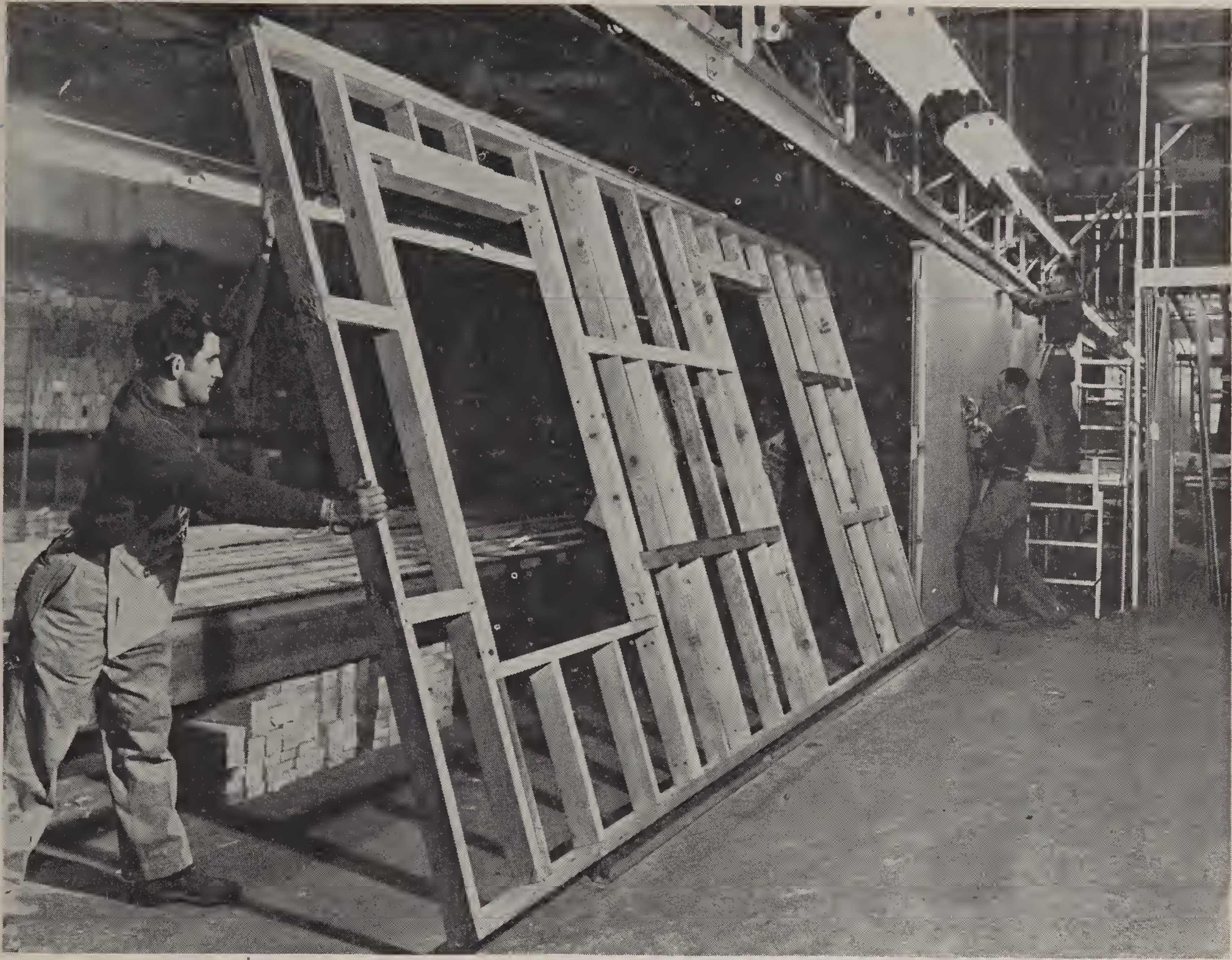


FIGURE 14–39.—Vertical continuous moving conveyor system used for assembling covers, insulation, and other parts to panel frameworks.

some gluing operations, treating with preservatives, and occasionally, wood and plywood bending.

14.30. Grading.—The importance of proper selection, or grading, of lumber to meet requirements of specific parts varies with the parts being fabricated. In normal times, wood users generally can buy lumber and plywood according to standard grades set up by the various commercial associations (ch. 4), and for most uses the lumber as graded by the supplier will not require further sorting. Where it is necessary, however, to buy lumber that has not been carefully graded, the prefabricator must select the better material from the shipment for use in the more critical parts of his houses. In general, such shop grading is done according to the requirements for specific parts of houses discussed in chapter 12.

Even the standard grades of lumber set up by producers must, however, be sorted for a few uses in some types of prefabricated houses. This is particularly true when selecting framing material for stressed-cover panels or trusses. Usually dimension lumber is purchased for this purpose (sec. 4.02112). Framing members of nominal 1-inch material for stressed-cover panels should be free from knots exceeding one-half inch in diameter and should not contain shake, splits, pitch pockets, or cross grain of a slope greater than 1 in 12. For thicker material slightly larger knots are satisfactory. Dimension lumber must be sorted to meet these requirements.

14.31. Machining. — Information pertinent to the various shaping and working operations necessary in the prefabricating plant is given in chapter 10.

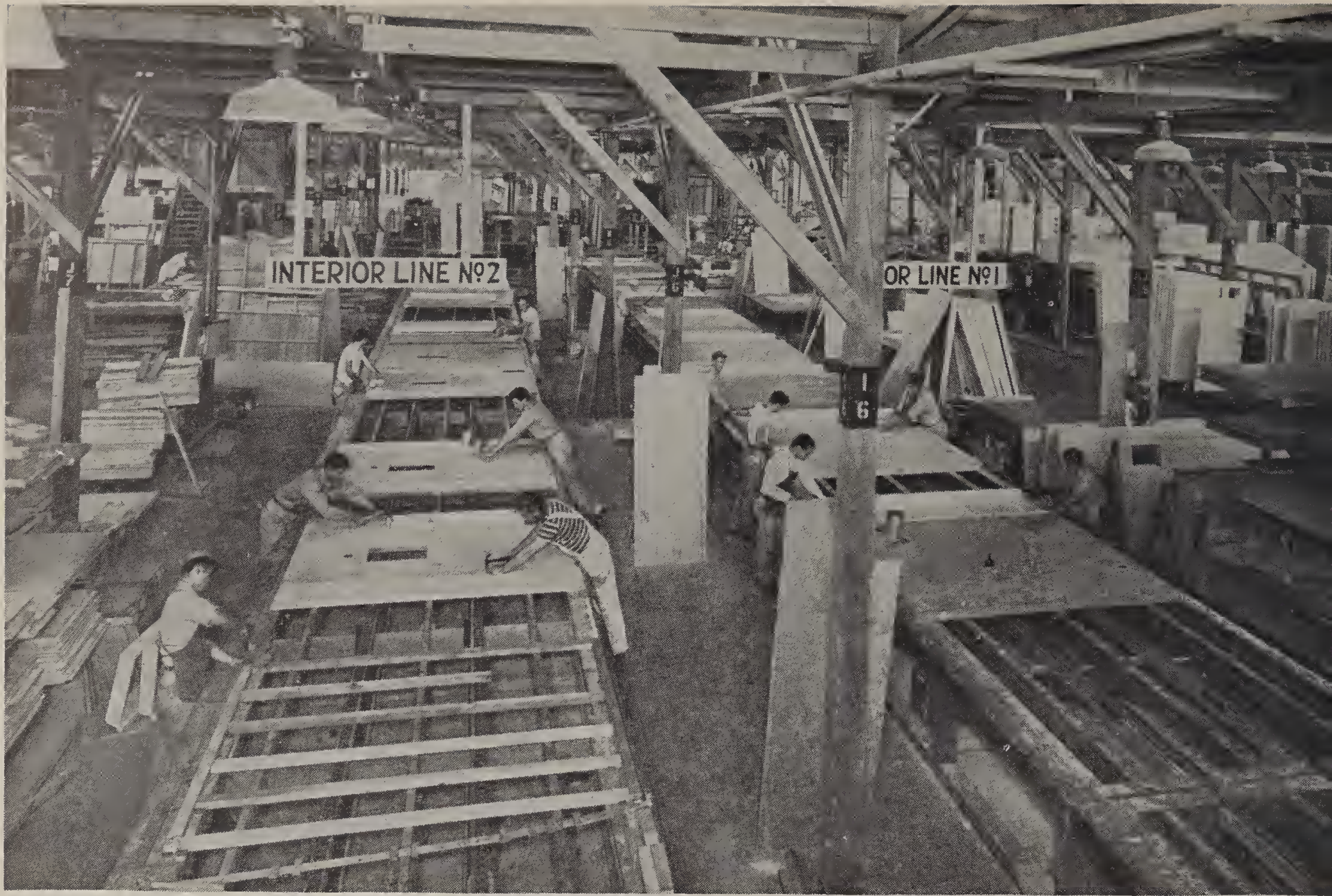


FIGURE 14–40.—Horizontal type of continuous moving chain conveyor system.

Economy in machining presupposes that the prefabricator will purchase those grades and sizes of lumber that most nearly meet the requirements for framing and other lumber used in the houses produced. Information on the various lengths, widths, and thicknesses in which lumber is furnished is given in chapter 4. For example, the most practical size of lumber for a $\frac{3}{4}$- by $2\frac{3}{8}$-inch panel stud would be a nominal 1- by 3-inch strip, the actual dressed dimensions of which are given in table 4–4 as 25/32 by $2\frac{5}{8}$ inches. The thickness of these strips, approximately $\frac{3}{4}$ inch, is suitable without further dressing; their width leaves $\frac{1}{8}$ inch to be planed from each edge, which is adequate to obtain the necessary close tolerance for gluing surfaces of a stressed-cover panel. The most suitable widths and thicknesses for other sizes of framing members can be similarly selected from table 4–4.

Aside from the labor and waste involved, reworking also entails the risk, especially with stock 2 inches and thicker, of encountering case-hardened lumber (sec. 9.125) that may cup when the inner portion is exposed, as in resawing. The likelihood of cupping can, of course, be reduced if thick lumber is conditioned, either by the producer or at the fabricating plant, to relieve internal stresses before it is resawed.

14.310. Machining Glue Joints.—As exacting as any machining operation is that involving surfaces for glue joints (sec. 11.31). Since the strongest joints are obtainable only between side-grain surfaces, a critical machining operation is often necessary in order to bring side-grain surfaces into contact. In many cases, the best compromise is the scarf joint (sec. 13.23). The purpose of this joint is to approximate side grain conditions as closely as possible when members are butted together. Such joints occur where framing members of unusual length, as in roof and floor panels, are needed; in laminated beams; and in plywood covers longer than 8 feet.

A device for the machining of scarf joints

FIGURE 14–41.—Continuous-belt conveyor system used to carry panels to and from high-frequency dielectric presses.

is shown in figure 13–12. The planer-type cutter head of this machine can be set at the angle that will cut the required slope of scarf. It should be adjusted so that a thin feather edge is produced in order that the mating surfaces can be joined with a minimum of overlap (fig. 13–13), so that as little sanding as possible will be necessary to produce a smooth joint. A well-cut edge will usually, in fact, make sanding unnecessary when the joint is made in a press such as is shown in figure 13–14.

Scarf joints can be cut in lumber by various methods. Where only occasional scarf cutting is necessary, it can be made with a hand planer. Where such splicing is a regular production step, scarf cuts should preferably be made with a jointer, shaper, single-end tenoner, or other cutting head by devising suitable jigs to hold members at the proper angle while the cut is made.

Figure 14–47 shows how a jointer and a single-end tenoner may be used to cut scarfs on the ends of long boards. The hand-feed jointer shown in figure 14–47, *A*, should be equipped with long tables to permit easy handling of boards to be scarfed. The jig shown should have adequate clamps to hold the member being cut firmly in place. The scarf cut should be made in at least two passes over the head, the final one being very light.

Such joints as the tongue-and-groove and the serrated or finger scarf are not recommended for joining of members endwise where strength is important because they are less efficient than a plain scarf with a flat slope.

The utilization of the single-end tenoner is practical for thin and relatively wide material (fig. 14–47, *B*). The jig shown is used with a tenoner having a nontilting head. If the head can be set at an angle, the material may be

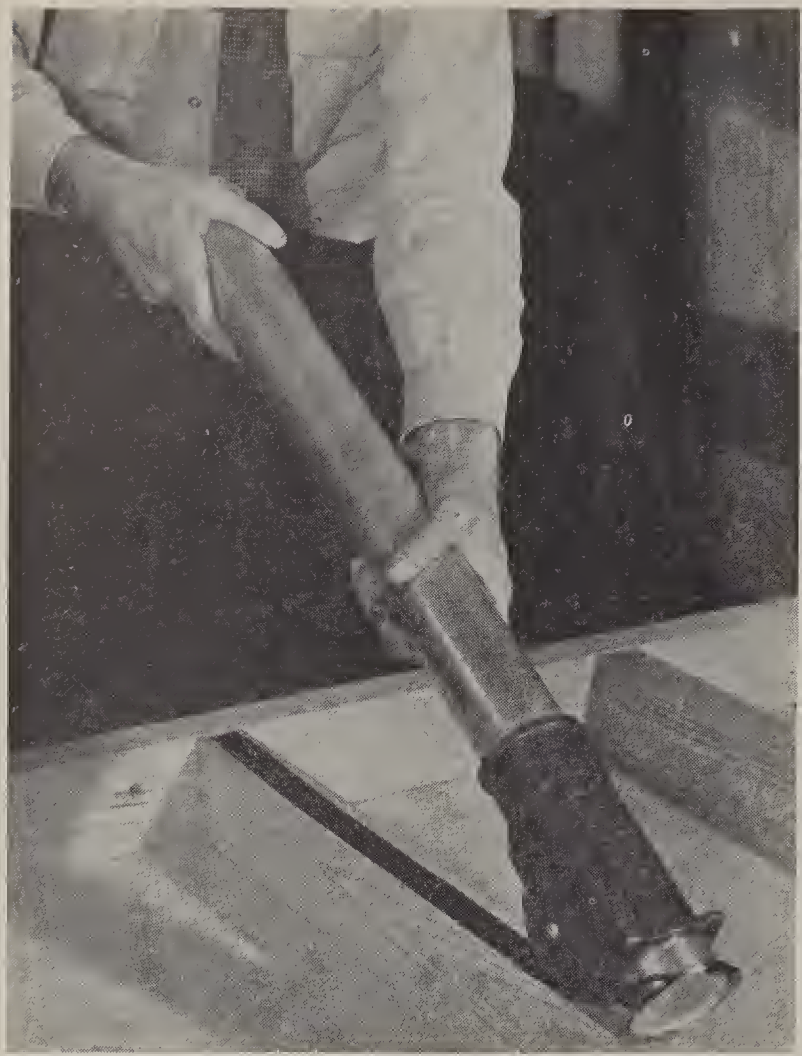


FIGURE 14–42.—Applying glue to a panel framework by means of a glue gun.

held in a horizontal jig. Tenoners of this type have heads not longer than about 7 inches; therefore, the maximum thickness of material than can be scarfed to a slope of 1 in 15 is about three-eighths inch. Since the cut is across the grain of the wood, considerable care is required to produce a surface of adequate smoothness. The spiral knives with which tenoner heads are equipped are advantageous in this respect. A backup block may be necessary to prevent splintering as the knives leave the cut.

14.32. Production of Curved Parts.—The need for producing curvature in wood parts of prefabricated houses seldom occurs, and is usually a matter of decoration rather than a structural problem. For decorative purposes, curved parts can be obtained with a band saw or shaper, using a template as a guide in making the cut. Where curved members are integral structural members of the house subject to stresses, however, sawing is seldom advisable, as it creates weakening cross grain. Wood bending must then be done. For structural parts, steam bending is usually practiced, steam at atmospheric pressure or hot water being used as the plasticizing medium. Plywood may be similarly bent, but molding is usually to be preferred.

14.320. Wood Bending.—Mild curvature can often be produced in wood simply by springing it in place and fastening it securely. Where the curvature is appreciable, however, steam bending is usually necessary. Successful steam bending is based upon (1) selection of the proper species; (2) seasoning o fstock; (3) preparation of bending blanks; (4) softening of the wood; (5) bending technique; and (6) fixing of the bent shape.

14.3200. Selection of Stock.—For bending to severe curvature, only hardwoods are suitable. Oak, elm, ash, hickory, and beech have long been the preferred species. But not all wood of even these species is suitable; the wood must be free of decay, and reasonably free of such defects as knots, worm holes, and surface checks although some small, sound knots near the ends, moderate surface checking, and scattered worm holes are permissible. Above all, the wood must be straight-grained. Cross grain with a slope steeper than 1 in 15 will cause excessive breakage and waste. Grain irregularities caused by knots and burls are as likely to cause breakage as is more extensive cross grain.

14.3201. Seasoning of Stock.—While green wood is often preferred for bending, wood can be bent at any moisture content from green to about 12 percent. Seasoned wood requires the addition of some moisture to the outer fibers, as well as heat, to prepare it for bending. Wood of exceptionally high moisture content, on the other hand, is not suitable for severe bending because hydrostatic pressure may cause compression failures. The tptimum moisture content of bending stock is probably around 30 percent, with the desirable range from 20 to 30 percent.

14.3202. Preparation of Stock.—Bending stock should always be kept to the minimum thickness consonant with use requirements and shrinkage after bending. Width should be greater than thickness; blanks several times as wide as the finished part are sometimes bent and sawed afterward to the required width. Breakage during bending is reduced by surfacing only the inner face, that against the bending form, and the two adjacent faces.

FIGURE 14–43.—Adaptation of hand-truck equipment for conveyance of built-in partition closets from assembly tables to finishing room and warehouse.

14.3203. Softening the Stock.—Stock should be softened in steam boxes or in boiling water for 20 minutes to 1 hour per inch of thickness. Oversteaming or overboiling may impair the strength properties of the wood.

14.3204. The Bending Operation.—After it has been softened, the stock should be bent as soon as possible to minimize loss of heat and moisture.

Mild bends can be made over forms without using a tension strap to protect the outer face of the stock, which is in tension during the bending operation. For more severe bends, a tension strap should be used in order to concentrate most of the stress on the inner face, against the form. A bending apparatus is shown in figure 14–48. This apparatus includes a tension strap and end blocks to hold the piece rigidly while it is being bent, compressing the inner, or concave, section and preventing the outer, or convex, section from stretching. Cushion blocks are placed between the metal end blocks and the ends of the stock; these are crushed as bending proceeds, and in so doing tend to relieve excessive pressure upon the ends of the piece. Clamps, dogs, wedges, or jacks can be used to hold the stock firmly against the bending form during the operation in order to counteract a tendency for the stock to spring back from the form.

The two sections of I-beam shown in figure 14–48, *b*, function on the reversed lever principle. They must be fully as long as shown, otherwise the stock may undergo reverse bends near the ends.

14.3205. Radius of Curvature.—There is a limit to the extent to which wood can be bent. Hardwoods such as oak and ash can, in extreme in-

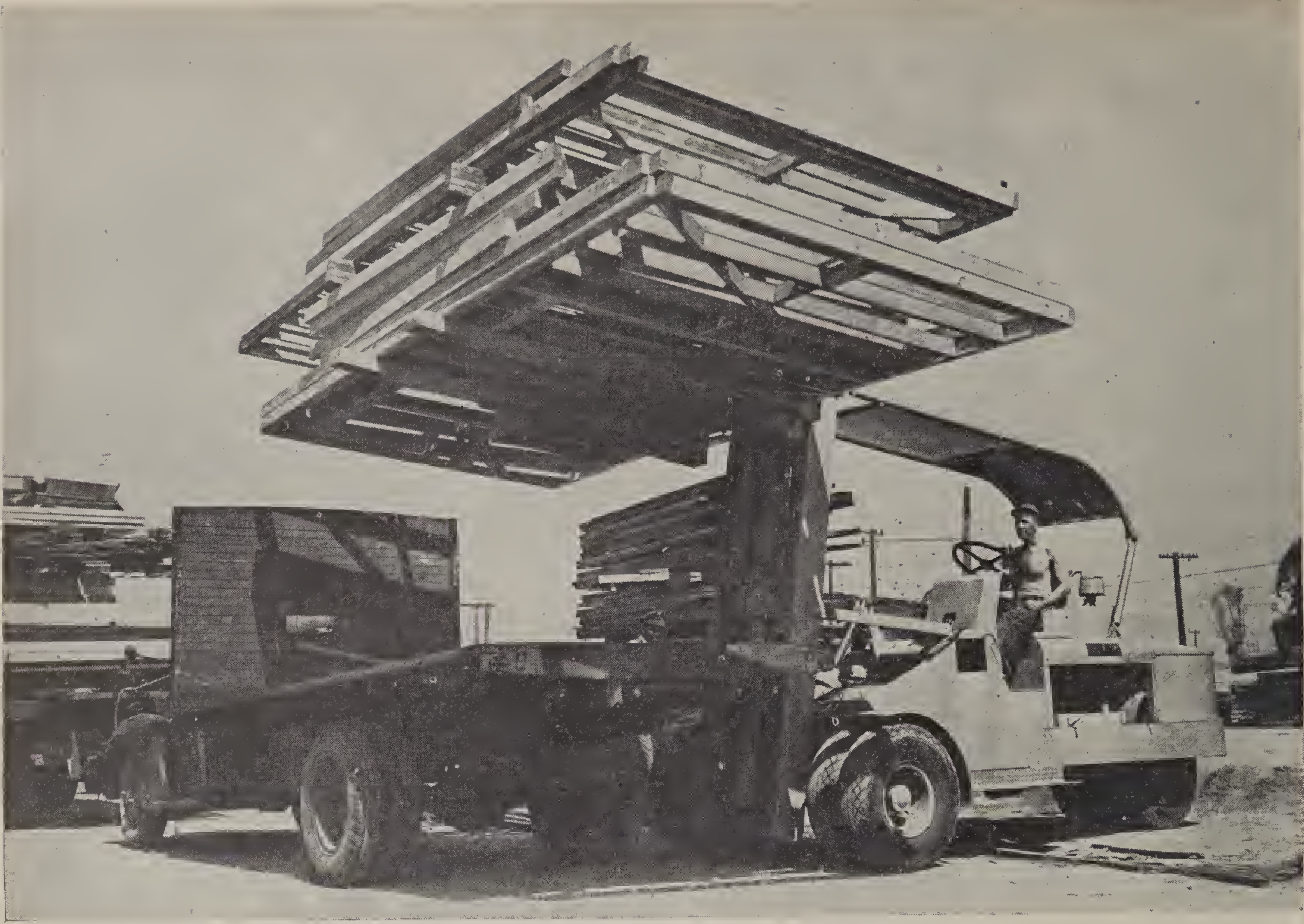


FIGURE 14–44.—Fork-lift truck used to load panels.

stances with careful selection of stock and careful manipulation, be bent to a radius as small as 3 to 4 times the thickness of the piece. For softwoods, which do not bend so readily, the limit is about 18 times the thickness.

14.3206. Fixing the Bent Shape.—In order to fix the bend permanently, the wood must be dried and cooled under restraint. Usual practice is to nail one or two stay-laths across the piece, connecting its ends, before it is removed from the bending form. With the stay-laths in place, the stock is allowed to season until it will hold its shape. Or the tension strap can be left on, its ends connected with a chain, while the piece is stored for seasoning.

14.321. Bent Laminated Wood.—Curved beams, arches, and other structural members can be produced by glue laminating (sec. 3.3). The technique of producing curved laminated stock has been developed greatly during the past decade *(14–6, 14–11)*.

14.322. Bending of Plywood.—Examples of the use of bent plywood in prefabricated housing are rare and confined only to specialties such as built-in cabinetwork. It appears reasonable, however, that with the development of the industry the use of bent or molded plywood will increase. The design possibilities offered by its utilization are considerable in such applications as interior partitions, stairwells, and perhaps even exterior walls.

The use to which the bent plywood part will be put should govern its thickness, number of plies, and direction of grain. Once these factors are established, the method of producing the bend can usually be determined. Bent plywood parts are more likely to undergo changes in shape with subsequent changes in moisture content than are molded parts that have been glued up, ply upon ply, over a mold. Bent plywood glued to a rigid framework such as the framing of a panel, however, is quite stable in form.

FIGURE 14–45.—Dip tank for treatment of lumber with antistain chemical. Note drainboard.

14.3210. Radius of Curvature.—The radius of curvature to which plywood can be bent without fracture decreases when (1) thickness is decreased; (2) face plies are laid more nearly parallel to the axis of load; (3) moisture content of the plywood is raised; (4) temperature of the bending form is raised; (5) quality of veneer is increased (particularly by minimizing cross grain); and (6) technique of bending is improved.

Reliable limitations on the curvature to which the grades of plywood commonly used in housing can be bent have not been established. For mild curvatures, plywood can be bent cold and dry provided it is solidly anchored in place. For more severe bends, plywood should be carefully selected; the face plies should be free from knots, burls, excessively sloping grain, and core gaps should be virtually absent in the cores and crossbands.

Only exterior grades of plywood can be softened with hot water without adverse effects upon the glue. Plywood can be softened somewhat by heating it. Use of a heated mandrel with dry, cold plywood is also useful (fig. 14–49). In preforming plywood by any wetting technique, there is a certain amount of springback that must be allowed for. Some operators bend soaked plywood on heated forms having a radius of curvature 20 percent sharper than the desired radius of the bend. Plywood that is to be bent to a short radius of curvature should be laid on the mold with the grain of the face plies parallel or up to 45° to the axis of curvature.

For more complete information on the technique of bending plywood to simple and compound curvatures the reader may consult reference *(14–3)*.

14.34. Control of Blue Stain.—Unless properly treated as soon as it is cut (within 24 to 48 hours, depending upon temperature conditions), sapwood lumber is subject to attack by

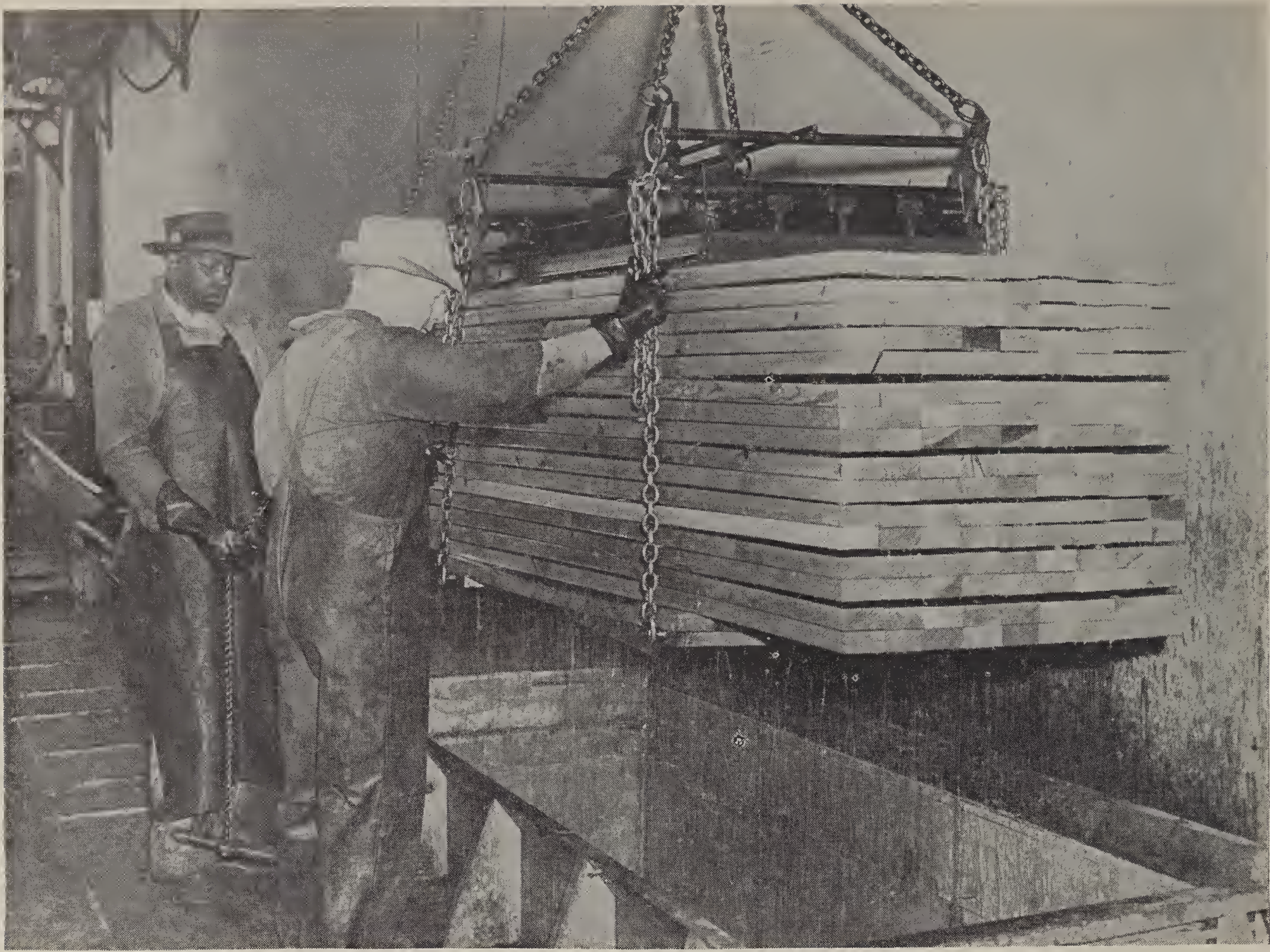


FIGURE 14–46.—Dip tank with hoisting device for antistain treatment of lumber. Green, unsurfaced lumber can be bulk-piled for treatment as shown.

blue-stain fungi (sec. 6.22). Once the bluish discoloration that indicates infection is visible, it is too late to treat lumber.

Some prefabricators purchase logs for cutting into lumber at the prefabricating plant. The most effective way of preventing blue stain in such lumber is to kiln dry it immediately, thus removing the conditions that encourage the growth of the staining fungi. If the lumber is to be air seasoned, blue stain development can be prevented by dipping the lumber in a solution of one of the chemicals available on the market for the purpose. Equipment suitable for dip treating is shown in figures 14–45 and 14–46.

Anti-stain treatment should not be confused with permanent preservative treatment for decay prevention. It is a temporary expedient effective only in preventing growth of the staining fungi until the lumber has been seasoned.

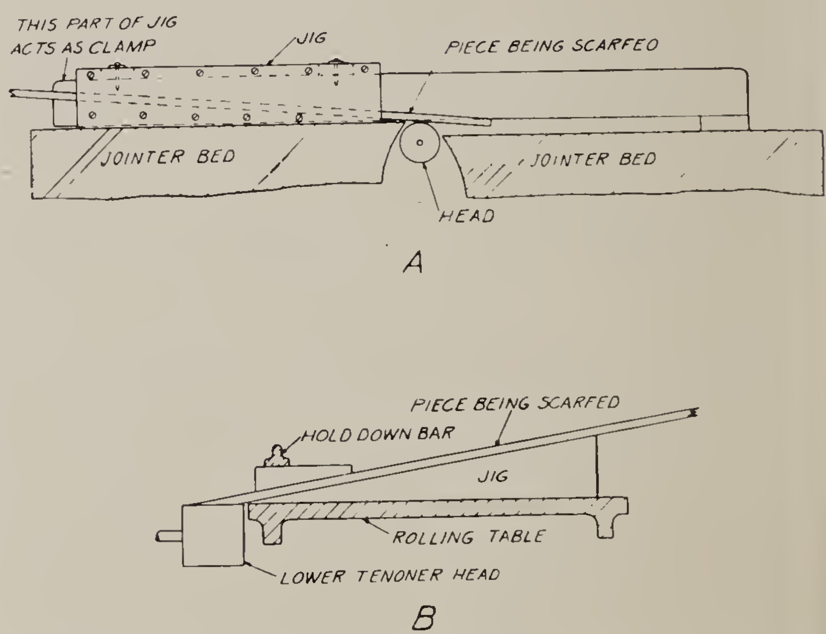


FIGURE 14–47.—Two methods of scarfing long boards. *A*, jointer, with stock clamped in inclined jig and passed over jointer head; *B*, single-end tenoner adapted with beveled jig and hold-down bar for scarfing.

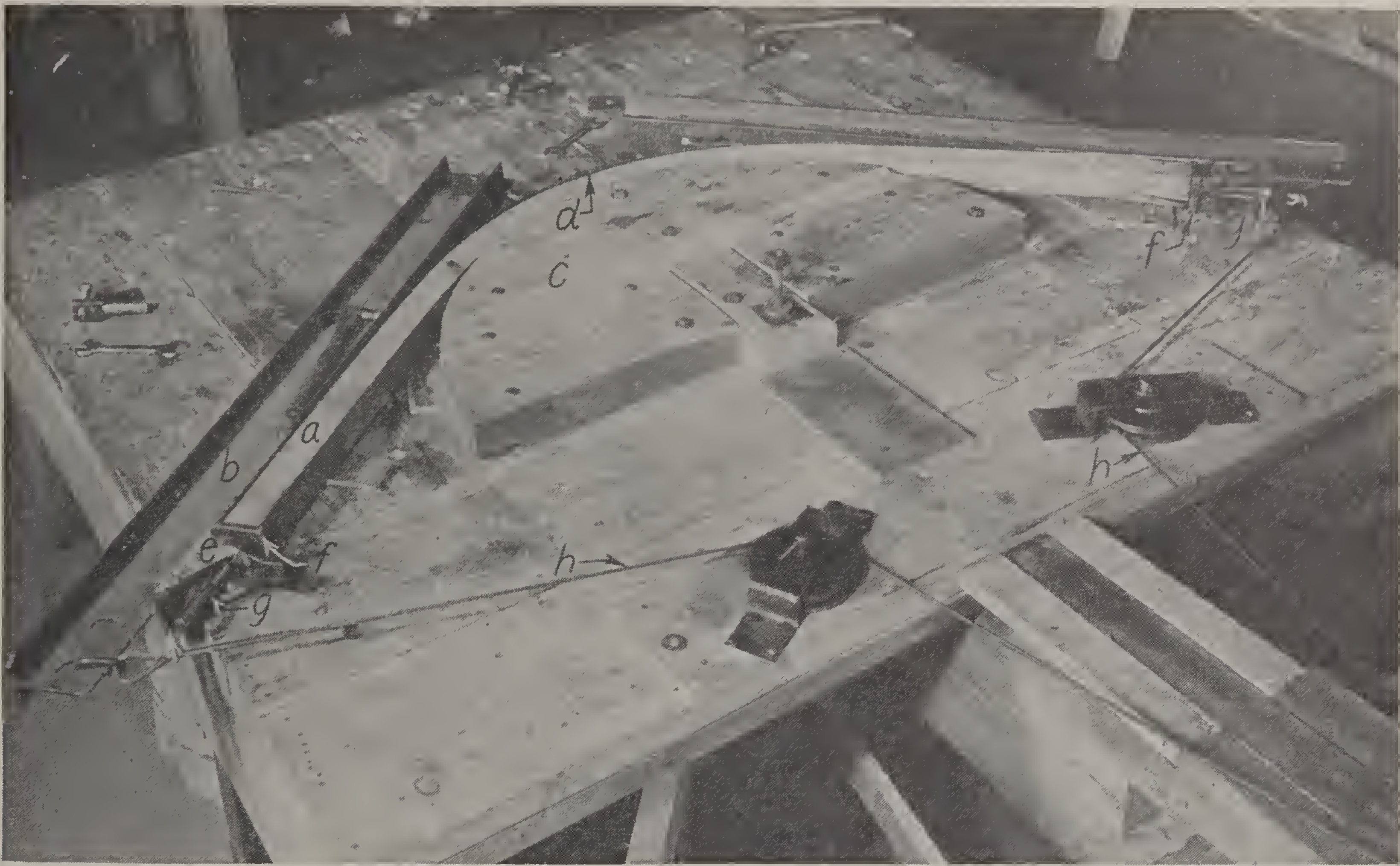


FIGURE 14–48.—Wood bending apparatus: *a*, stock being bent; *b*, two sections of I-beam used to prevent reversal of curvature at ends of stock; *c*, bending form; *d*, strap, welded near its ends to *b*; *e*, end abutments welded to strap; *f*, steel plates bearing against ends of stock; *g*, end screws threaded through *e* to apply pressure to steel bearing plates; *h*, steel cable to pull the stock into position around the form. End screws *g* must be carefully centered against ends of stock, otherwise buckling, as shown on the right end, is likely to occur.

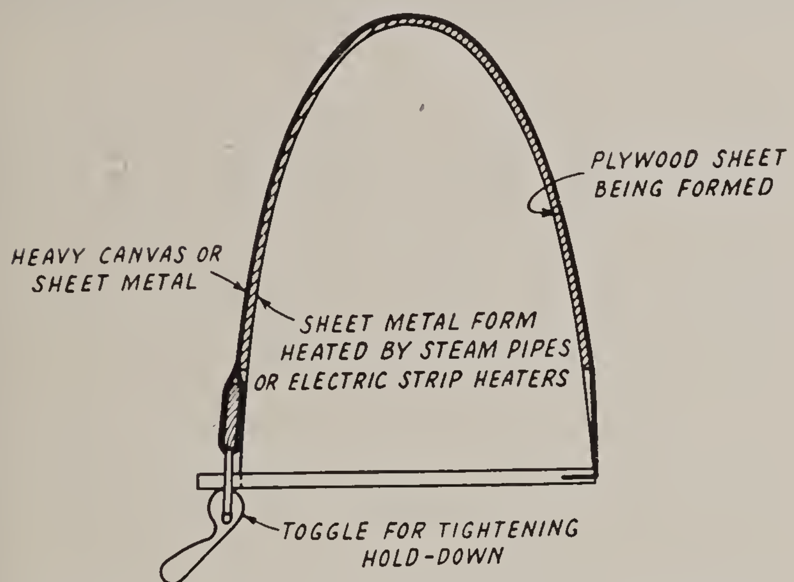


FIGURE 14–49.—Steam-bending form for plywood.

14.4. PLANT ASSEMBLY OPERATIONS. — The basic assembly operations involved in production of panelized construction usually comprise (1) assembly of framework; (2) installation of necessary wiring, framing for fixtures, duct work, water pipes, and similar equipment; (3) attachment of the framing of window and door openings; (4) fixing insulation and vapor barriers in place; (5) attachment of cover materials and window and door trim; and (6) painting and other finishing. For information applicable to unit assembly operations, the reader is referred to the discussion of site assembly operations in section 14.8.

14.40. Assembly of Framework. — Virtually all prefabricators assemble panel frameworks on jigs (sec. 14.2130). The principal factor involved is to match all framing joints as precisely as possible, so that the surfaces to which covers will be attached are in a single plane at all joints. The need for precision varies somewhat with the type of construction. Nailed panelized construction of conventional framing, sheathing, and siding is less critical than, for example, glued stressed-cover construction, as discussed in section 14.111.

Framing may be assembled with nails, as shown in figure 14–50, with corrugated fasteners (fig. 14–51) of the type used in box manufacture, or some other mechanical fastening. The type of fastening selected depends upon

FIGURE 14–50.—Nailing members of a panel framework together on a jig. Accuracy of joining with this type of jig, which has no continuous top surface, depends largely upon the workman, who must life the members into exact position before nailing them together.

the type of construction. Framing joints are rarely glued.

In a panel frame such as that shown in figure 14–51, corrugated fasteners are probably adequate, since their principal purpose is to hold the light framework securely together during handling while covers are glued on and the glue is curing. For larger frameworks of stressed-cover type, nailed joints are advisable to secure adequate strength for handling in further assembly operations.

Nails, corrugated fasteners, or other fastenings that are driven into the gluing surfaces of framing members, should be driven at least flush with the surface of adjoining members to avoid interference with attachment of the cover when gluing pressure is applied with nails.

14.41. Installation of Equipment.—All necessary electric wiring, backup plates for switches and other electrical fixtures, furnace ducts, framing for heat registers, water and plumbing pipes, gas lines, and similar household equipment must be installed before the covers are attached to the panels, unless definite provision is made otherwise. Some prefabricators design their panels so that some of these appurtenances can be installed on the site; figure 14–24, *C*, shows a wall panel with the inner face open at the bottom and with studs bored for electrical conduit, so designed that a baseboard conceals the opening in the finished house. The general trend, however, is to install as much of the household equipment as possible at the factory in order to shorten site assembly time. Among service panels commonly produced are units containing all plumbing and water pipes necessary for both kitchen and bathroom (fig. 14–21), usually as an interior partition to avoid the necessity of insulating such pipes against cold.

Openings for duct work and heat registers in stressed coverings usually require some fram-

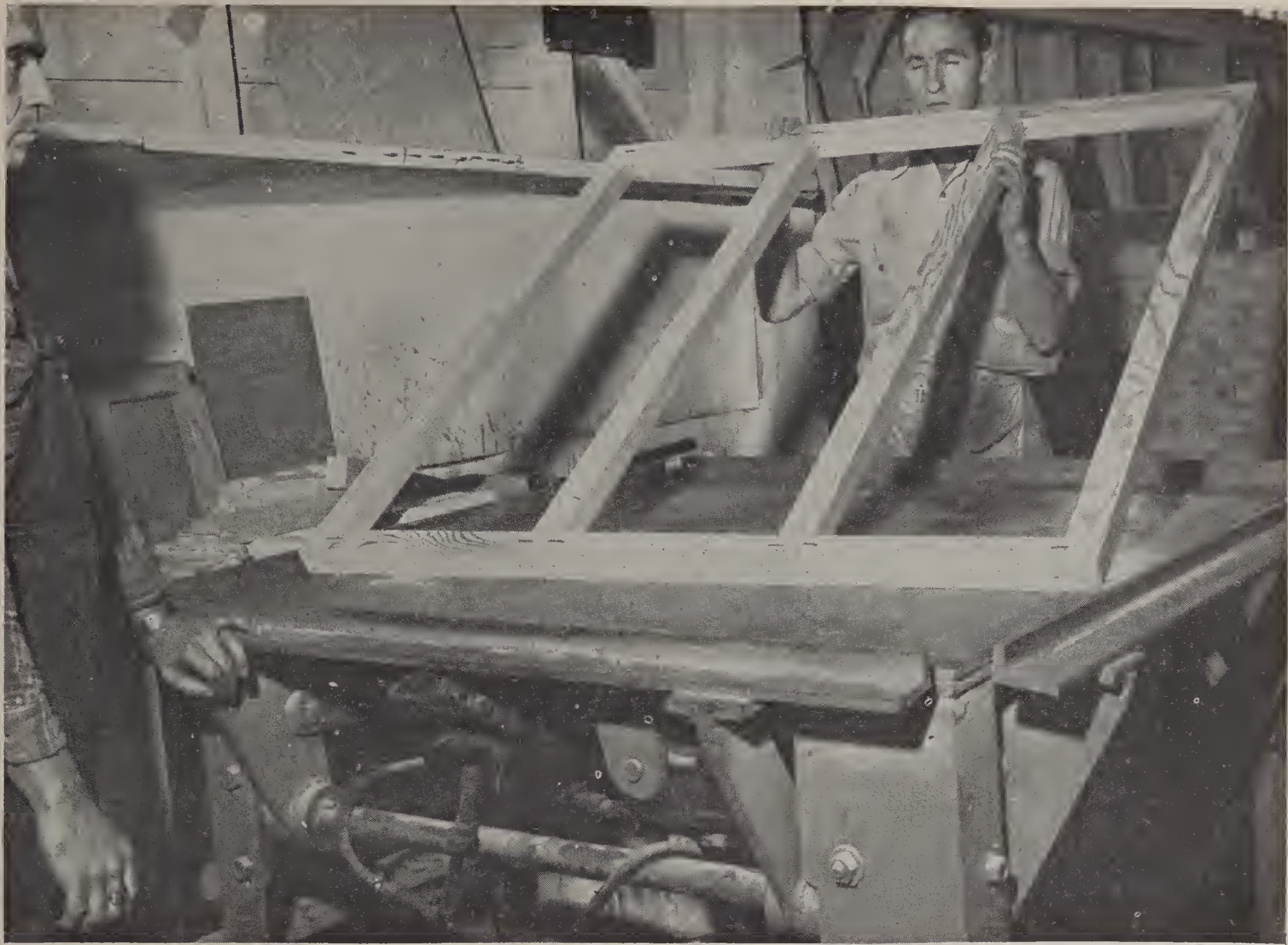


FIGURE 14–51.—Panel frame assembled on a clamp-type jig. Corrugated fasteners used.

ing to offset their effect upon panel strength, especially if near the center of the span of a floor panel (sec. 14.11111). It may also be necessary to reinforce the edges of the plywood about the opening to provide a base for fastening registers with screws. Figure 14–52 shows a plywood base for an electric switch framed in a panel before covering is attached.

14.42. Installation of Doors, Windows.—It is, generally speaking, a simple matter to attach door and window framing, or the complete unit, in place in a properly framed panel. A separate jig may be used for each combination of doors and windows, although frequently a single large adjustable jig may be used to assemble sections of various lengths. The guide blocks of the jig automatically position the door or window framing as well as the main studs and plates. To this rough framing the finished door and window framing is then attached as in conventional housing; trim, however, generally cannot be installed until the wall covering has been attached.

Modular stressed-cover panels are often cut open for windows after the cover is installed (fig. 10–15). These panels are, of course, properly framed for such attachments on the framing jig. A template of full panel size (fig. 14–53) is laid on the panel to guide the cutter in making the cut in the proper place. Templates are highly useful in all such cutout operations where framing is concealed. They are generally made of plywood, a material that, under normal shop conditions, changes dimension scarcely at all due to shrinking and swelling. Templates may be made of solid wood of a species that shrinks and swells little, such as white pine.

14.43. Installation of Insulation.—Various types of insulation are available (sec. 8.112) and the method of installation varies somewhat with each. The principles and functions of insula-

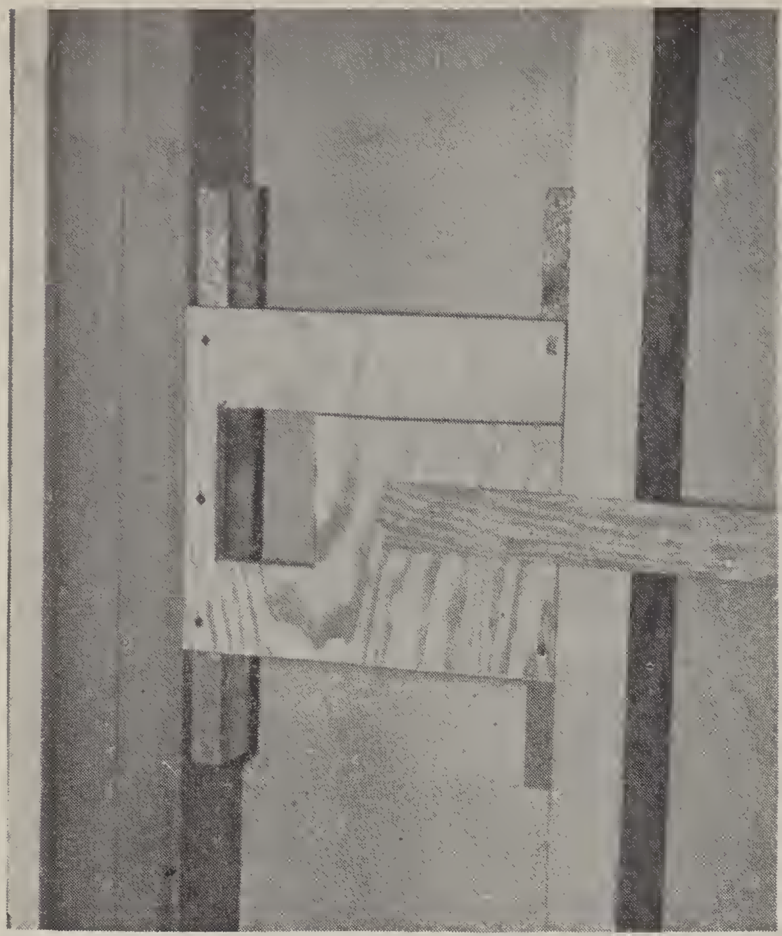


FIGURE 14–52.—Plywood base for wall switch framed in panel before covering is attached.

tion are discussed in section 8.1 and information on installation requirements is given in section 14.14. Additional information on vapor barriers is presented in sections 8.2 and 14.15, together with a discussion of the related problem of ventilation.

Blanket insulation is usually installed between studs and joists by stapling with a hand stapler of the type operated with a hammer. The principal precaution necessary is to see that the insulation fits tightly to the frame to prevent heat loss through this seam. Where the insulation incorporates a vapor barrier, particular precaution must be given to adequate closure of the joint. Stapling must be secure enough also to prevent sagging of the insulation during the life of the house. Unless the blanket is thick enough to fill completely the space between studs, it should be centered with an air space on either side. One method of installing such insulation is shown in figure 14–36. Some prefabricators fasten the insulation with wood or heavy fiberboard nailing strips to make a tight joint between insulation and framing.

Foil insulation is usually installed as a curtain within the panel, being tacked or stapled in place or mounted on wood strips as shown in figure 14–1. The latter method permits use of double-face foil as a double curtain creating three air spaces and thereby increasing its insulating efficiency substantially (sec. 8.111).

Rigid fiberboard insulation can be tacked to base strips nailed to studding or inserted in precut grooves in the studding (fig. 14–24, *E*). The latter method is the simpler from an assembly standpoint. Fill-type insulation is simply poured or packed between the framing members; the manufacturer's recommendations as to amounts should be closely adhered to. If insufficiently packed, the material may settle; on the other hand, overpacking is wasteful and reduces its insulating effectiveness to some degree.

14.44. Installation of Vapor Barriers.—Vapor barriers are often provided with blanket types of insulation, as an integral part of the paper covering. Foil insulation serves a dual function as a vapor barrier. Rigid fiberboard may or may not have a vapor-resistive coating on one or both sides. Where the barrier is applied on only one side of insulation, this side should always be on the warm, or inner side of panels. Use of fill-type insulation calls for installation of a vapor barrier on the warm side. Barrier materials and methods of their installation are discussed in section 14.15.

14.45. Installation of Covering.—In its broadest sense, coverage is anything that is put over framing to afford protection from rain, wind, and other weather elements. In the conventional house, coverage includes sheathing, building paper, siding, shingles or other roofing, lath, plaster, paint, and wallpaper. While insulation and vapor barriers function as coverage, they are not commonly regarded as quite the same thing. Practically, it is the exterior coverage—sheathing, building paper, and siding—that acts as a weather buffer.

These functions of coverage are carried over into the panelized forms of conventional construction prefabricated in the factory. As previously pointed out (sec. 14.1110), design of such houses virtually ignores the strength of the covering materials, relying principally upon the framing to carry all loads. Consequently, coverage is attached largely by the same nailing techniques as are followed in conventional site

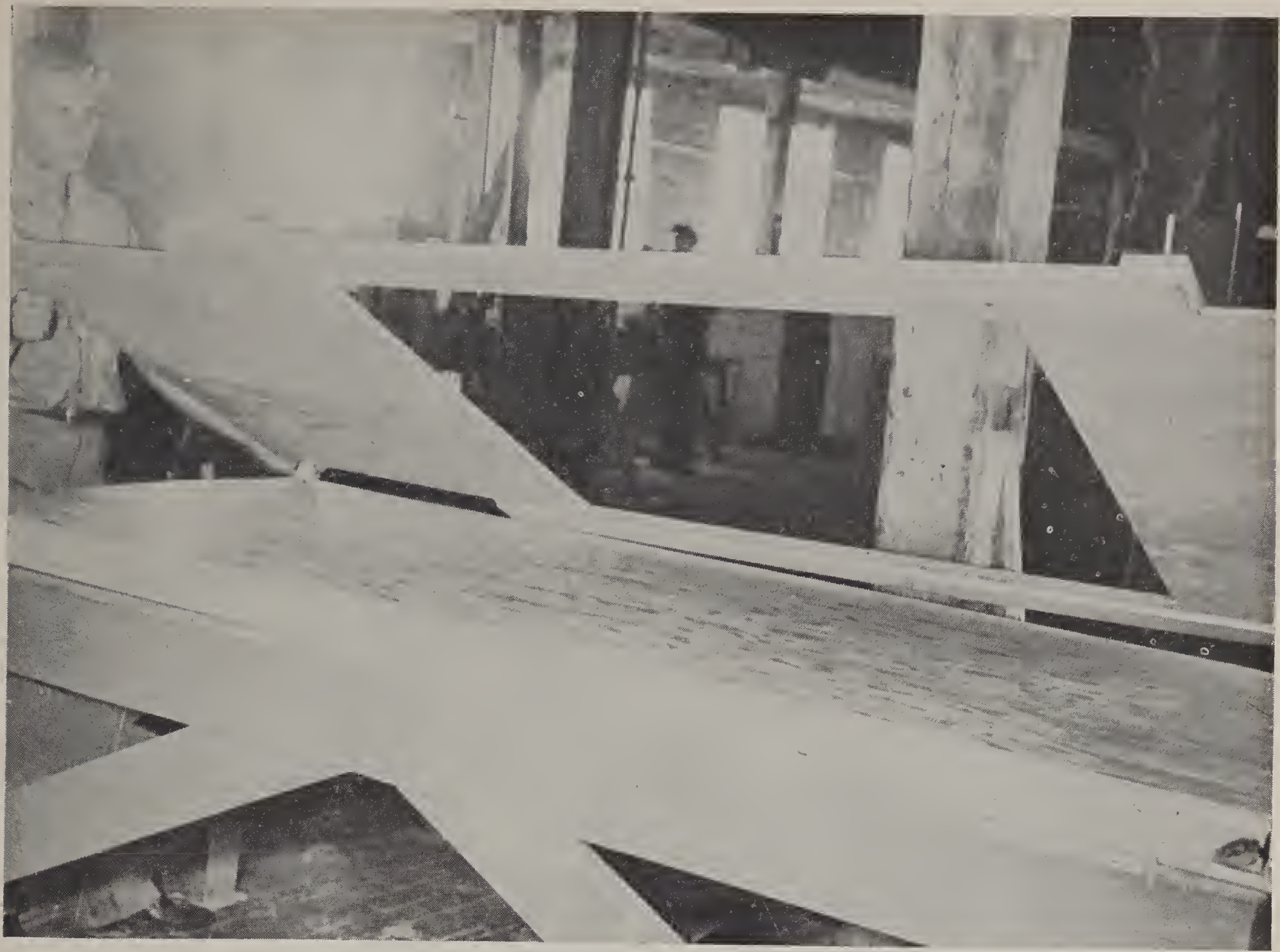


FIGURE 14–53.—Template used to guide window cutout in stressed-cover modular panel. Note guide strips on either side that lap over panel sides.

construction. Some builders of this type of prefabricated construction depart from conventional materials to the extent that they glue plywood to the framing in place of conventional nailed wood sheathing; likewise, plywood may be glued to the inner surfaces of such panels instead of lath or plaster board. While such practices increase the structural strength in some respects quite markedly (tests show that plywood glued in place is greatly superior under racking loads to nailed wood sheathing) the added strength and rigidity are likewise ignored.

This neglect of the strength of coverage in design is the principal engineering difference between nailed panelized construction, including its variations, and the newer stressed-cover construction, in which the strength properties of the coverage are considered in developing the strength of the structure as a whole. This basic difference in design is reflected in the greatly differing techniques employed in fixing coverage to the frameworks of the two types of panelized construction. Obviously, coverage must be attached to stressed-cover construction with much greater attention to joint and other details than is the case with nailed panelized construction and its variants.

14.450. Attachment of Coverage to Nailed Construction.—Figure 14–39 illustrates an effective factory technique for applying coverage to nailed panelized construction. The vertical conveyor system permits attachment of sheathing, building paper, and siding to framework sections preassembled on a jig and lifted into place on the conveyor line. A somewhat similar vertical assembly method for flooring panels is shown in figure 14–54.

This type of conveyor is well adapted to attachment of coverage with glue; one manu-

FIGURE 14–54.—Attaching prefinished flooring to panels consisting of plywood subfloor, cleats, and building paper. Cleats are spiked to conventional joists during site assembly.

facturer uses it to glue plywood sheathing on wall sections, using glue guns and nail pressure. Over the plywood, building paper is applied with nailing strips, siding then being nailed over the strips to create a small dead-air space. The inner face of this panel may be left open for application of lath and plaster on the building site, or it may be covered with plywood or some other sheet material in the factory. Plywood may be applied in standard sizes or preassembled in large room-length sizes for attachment on the conveyor line. One manu-

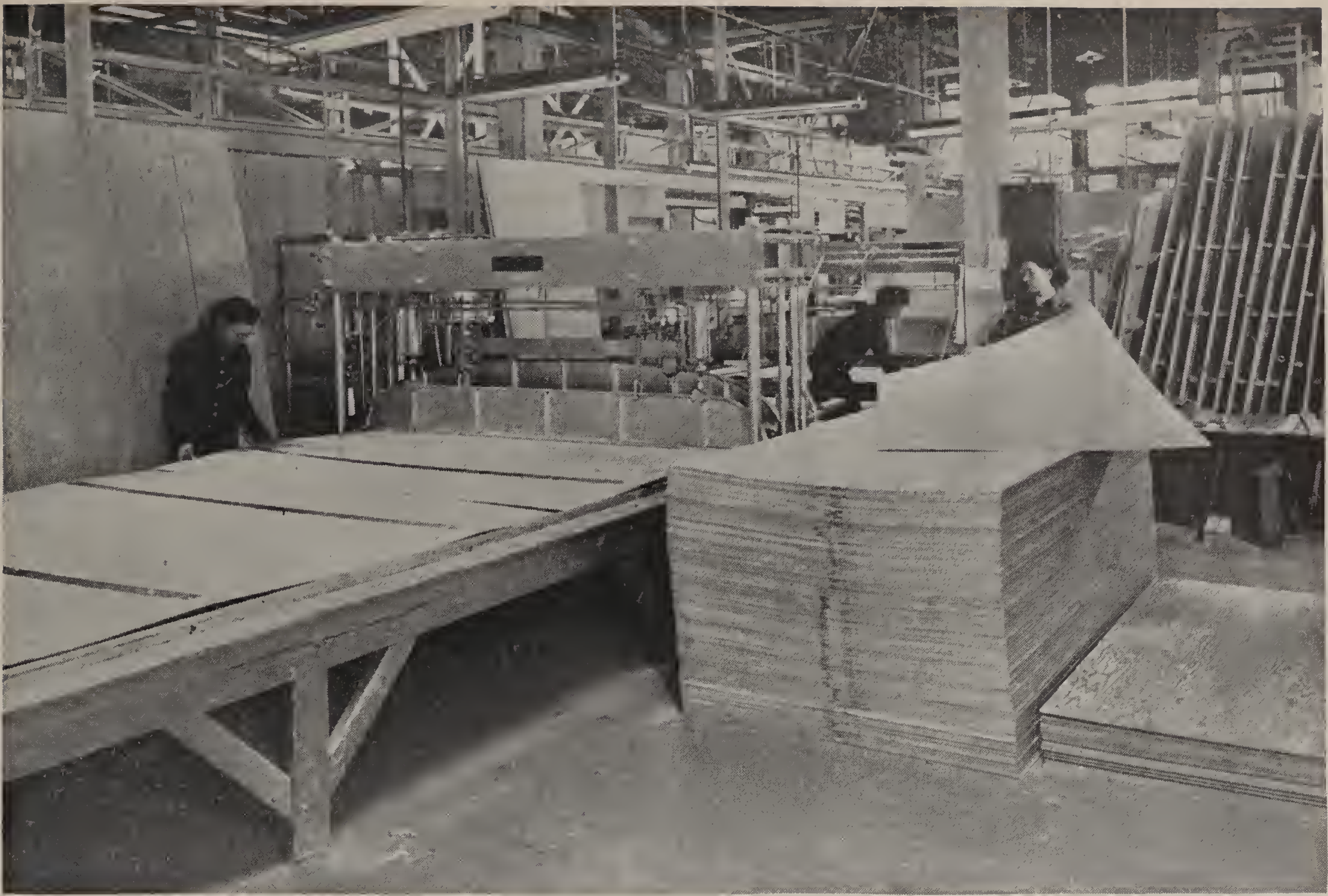


FIGURE 14–55.—Edge-gluing plywood by means of splice plates in a firehose press equipped with electric resistance grids for rapid heating of the glue and hydraulic pressure.

facturer's method of joining plywood for attachment in room-length sheets by butt joining with glued splice plates is shown in figure 14–55.

It should be noted that, while this method of edge-joining plywood into large sheets is suitable for the purpose discussed above, the joint formed is generally too weak for use with stressed-cover construction. A scarf joint with a slope of 1 in 15, formed as discussed in section 14.312, would much more nearly approximate the strength of the plywood.

14.4500.Shingles for Wall Covering.—The use of shingles for wall coverage over sheathing and building paper has had a considerable vogue with nailed panelized construction. The usual rules for applying it on conventional wall and roof construction are followed in panelized construction, as agreed upon by a majority of the shingle industry under Commercial Standard CS31–38, U. S. Department of Commerce. These rules call for an exposed surface on walls of not more than $6\frac{3}{4}$ inches of a 16-inch shingle. Figure 14–56 shows workmen applying the bottom course of shingles to a panel. This course of shingles extends about 8 inches below the bottom plate of the panel so as to overlap the subfloor construction. Figure 14–57 shows a panelized exterior shingled wall so constructed that, at the panel joints, alternate shingles will overlap about 2 inches to conceal the panel joint. Unless packed with care, overlapping shingles are likely to be damaged in shipment. The method requires considerable on-site tailoring to present a finished appearance.

Somewhat reversing the usual trend in prefabrication is a method of exterior wall construction by which the interior coverage, consisting of plywood nail-glued to the framework, is factory-installed while the exterior coverage is site-applied. This method permits use of any exterior coverage by conventional methods, thus effectively concealing panel joints (fig. 14–58). Interior wall partitions are assembled with nail-glued plywood on both sides of framework; floor and ceiling panels

FIGURE 14–56.—Applying bottom course of shingles over sheathing and building paper of nailed panelized construction. Bottom course of shingles projects below bottom plate of panel sufficiently to lap joist header.

are covered with nail-glued plywood on one side.

14.451. Attachment of Coverage to Stressed-cover Construction. — Stressed-cover construction requires the most effective joint possible to make between cover and framework. With wood construction, glue is the strongest bonding material yet developed. Because it forms a continuous bond between the mating surfaces of joined parts, it can carry greater loads than mechanical fastenings. The quality of a glue joint is determined by tests under shearing loads; if shear failure is principally in the wood adjacent to the glue bond in such a test, the strength of the bond is considered to approach that of the wood in shear. Glue bonds in stressed-cover construction should meet this test (sec. 11.39).

14.4510. Gluing Technique for Stressed-cover Construction.—The principle factors of good gluing technique are discussed in section 11.3. The factors involved in panel assembly—assuming that such others as moisture content and machining have been given proper attention in seasoning, storing, and subassembly operations —are (1) preparation of glue for use, (2) working life of the glue, (3) glue spread, (4) assembly time, (5) gluing pressure, and (6) curing of the glue. The techniques affecting each of these phases of the gluing operation as discussed in section 11.3 will, in combination with good workmanship, help assure consistently good bonding of coverage to framing members. "Good workmanship" is specified because the best glues and techniques can be nullified by carelessness in some seemingly trivial respects. Among these are cleanliness, proper mixing of the glue ingredients, care in spreading, avoiding the use of water or some other liquid to thin glue that has begun to thicken, proper attention to spacing and driving of nails, proper pressures and pressing periods in presses, and care in handling assembled constructions while the glue is curing.

Gluing methods in use in prefabricating plants range from nail gluing to use of automatic presses, either cold or heated with steam, electricity, or high-frequency dielectric current. The most common method is nail gluing, the glue being spread on the framing members with glue guns similar to that shown in figure 14–42. Where pressure is applied by means of presses, glue spreading is commonly done with spreaders of the roller type, such as that shown in figure 11–5. Various pressure devices are shown in figure 11–6.

14.45100. Gluing Pressure. — Gluing pressure must be ample to assure intimate contact of the gluing surfaces while the glue sets. There is no hard-and-fast rule that permits establishing one gluing pressure as the optimum for all gluing operations, because the pressure required is affected by such variables as consistency of the glue, stiffness of the material, and smoothness of the surfaces. This is demonstrated by the fact that good glue joints can be obtained with nail gluing, where pressure is low, and with presses capable of exerting several hundred pounds of pressure per square inch of glue-joint area. The maximum permissible gluing pressure is ordinarily fixed by the crushing strength of the wood. Since the wood surfaces are seldom perfectly true and smooth, the minimum gluing pressure must ordinarily

FIGURE 14-57.—Panelized shingled wall with alternate courses of adjoining panels overlapped about 2 inches to conceal panel joint.

be great enough to deform the members to a degree sufficient to insure intimate contact. Consequently, lower pressures, as obtained by nail gluing, are often adequate for gluing thin plywood to heavier members, while comparatively high pressures will be required if two heavy members are to be glued together. Whenever feasible, however, the higher pressures are advisable because lack of adequate and well-distributed gluing pressure is a much more frequent cause of defective glue joints than too much pressure.

With good nail gluing, pressure is applied successively at concentrated points close together. If nailing is properly done, the variations in pressure between nails are held to a minimum, and the variations in cover thickness due to manufacturing tolerances, as well as the variance from complete flatness of the plywood sheet and whatever slight irregularities may exist in the framing member, are compensated for by the method in which pressure is applied.

A press, on the other hand, must exert sufficient force on the members to compensate for irregularities due to tolerance variations, machining faults, and slight warp or other defects in the framing members and plywood covering. Pressure is exerted at all points at the same time, so that there is no possibility, theoretically, of compensating for irregularities in the mating surfaces as occurs in nail gluing.

14.45101. Factors Affecting Nail Gluing.—The important factors in nail gluing are (1) nail spacing, (2) proper driving, (3) proper nail size, and (4) nailing from the midpoint of the panel toward both edges.

An insufficient number of nails will inevitably result in an unsatisfactory glue joint. A uniform pressure condition is approached when nails are closely and regularly spaced. Experience indicates that, for one-fourth inch Douglas-fir plywood, satisfactory joints should be obtained with threepenny casing nails spaced 3 inches on center; for three-eighths inch to five-eighths inch plywood, sixpenny casing nails

FIGURE 14–58.—Exterior wall panels with outside coverage applied at site to conceal exterior panel joints.

spaced 3 inches on center should be satisfactory for pressure purposes.

Proper driving means that nails should be driven so that the heads seat flush against the surface. Nails that are not properly seated do not apply the full pressure of which they are capable. This does not mean that the nails should be set; hammer pressure is sufficient to drive them home without marring the surface of the surrounding wood if the workman is careful. Good driving is particularly important with nailing devices using clips of nails and operated with hammers.

The nail must be driven deeply enough into the framing member to assure development of adequate resistance to withdrawal and consequent maintenance of pressure. In woods of low density, the nail should penetrate into the member receiving the point a distance at least twice the thickness of the coverage; in woods of high density, at least one-half the nail should be embedded in the framing. For nailing purposes, softwoods can be considered as among the less dense species because they may vary considerably in specific gravity (table 3–1).

The direction in which nailing progresses in attaching covering to a stressed-cover panel is important chiefly in that it helps to avoid wrinkles and bulges that would prevent complete contact between frame and cover. By beginning at the midpoint in a panel and working toward both edges along the length of the panel, the cover is laid down uniformly. If nailing is from both edges to the midpoint, the cover tends to bow slightly upward, requiring much greater pressure to bring it into full contact with the framing than may be possible with nailing pressure, and the result, once the glue has cured, will be an open joint. Even if pressure is adequate to bring the cover down, stresses are set up in the plywood that may be sufficient to shear the glue bond during the life of the structure.

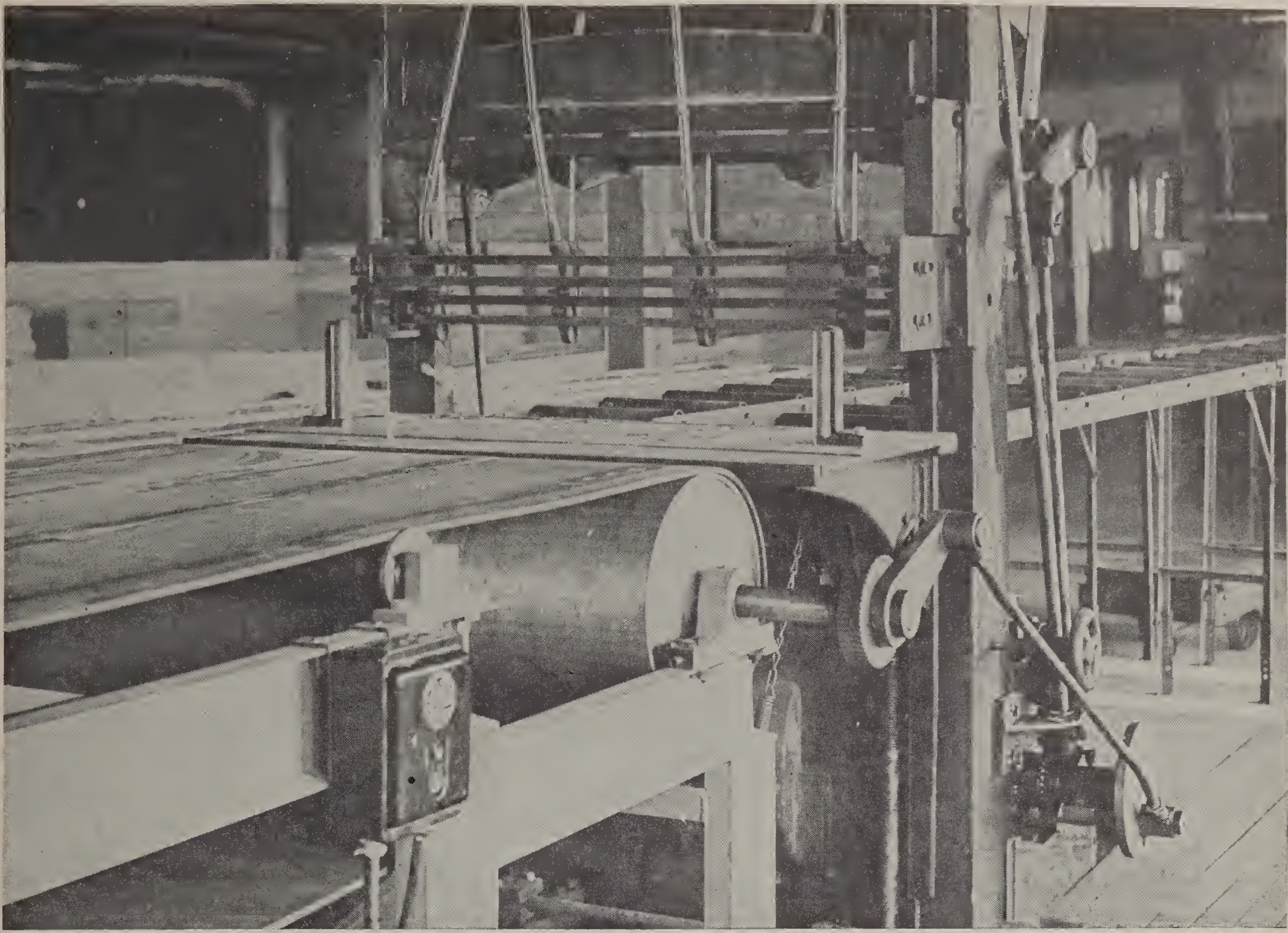


FIGURE 14–59.—Nailing machine used to attach covering to stressed-cover panels of unusual length. Note belt conveyor table.

Nailing machines have been adapted to use in nail gluing of long stressed-cover panels such as those designed for floors and roofs (fig. 14–59). These machines insure accurate spacing of nails. Occasional adjustments may be necessary, however, to make certain that nail heads are driven flush with the cover, and panels should be frequently inspected to see that the machine is driving nails full depth.

14.45102. Factors Affecting Press Gluing.—The essentials of good gluing when presses are used are (1) adequate spread, (2) control of assembly period, (3) adequacy of pressure, and (4) maintenance of proper temperature for the glue used for a period sufficient to achieve the degree of cure needed to permit handling and storing.

For press gluing, glue is usually applied with a spreader to both sides of the assembled panel frame. The frame is then placed on standards equipped with triangular strips, so that the lower side rests on the apex of the triangle while the cover is lightly tacked to the opposite side; triangular strips are used to reduce the area of contact between supports and framework to the minimum, thus avoiding undue interference with the glue on the frame. When the top cover has been tacked in place, the frame is turned over and the bottom cover similarly positioned (fig. 14–60). Only sufficient tacks are needed to hold the covers until the assembly can be placed in the press. When high-frequency, dielectric presses are used, these tacks should be set below the surface of the covers to avoid short circuiting.

In moving panels from the spreader to the press, they should be handled with great care. A belt conveyor system used by one manufacturer for this purpose is shown in figure 14–41. Another method of moving panels is shown in figure 14–34, consisting of a jig used to position coverage on the framework and mounted

FIGURE 14–60.—Placing cover on a frame.

on trucks for easy coveyance of the panel to the press without removing it from the jig.

Pressures recommended for presses usually fall within the range of 100 to 150 pounds per square inch for softwoods, and from 150 to 200 pounds per square inch for the denser hardwoods.

Various types of presses used in prefabricating plants include the high-frequency dielectric presses shown in figures 11–11 and 11–12; the cold press shown in figure 14–61, and the multiple-opening hot press shown in figure 14–62. It is highly important that the press be built strongly enough so that its structural parts will not bend under high pressures, because even slight bending will cause uneven distribution of gluing pressure. For example, if the I-beams that distribute the pressure from the pistons of the press shown in figure 14–61 should bow under load, pressure would be unevenly distributed over the panels. The bed of the press should also be substantial enough to take normal pressing loads without bowing.

Hot presses permit rapid curing of the glue and eliminate the need of retaining clamps or other methods of maintaining pressure during a long curing period. The high-frequency dielectric presses shown in figure 11–12, for example, cure glue sufficiently for removal of the panels in 5 to 6 minutes. In room-temperature operations it may be necessary to maintain pressure for several hours.

Cold presses can be used in combination with clamps and curing chambers to speed handling and increase press capacity. One manufacturer stacks freshly glued panels in a press shown in figure 11–7; after pressure is applied, clamps are attached to the bundle of panels to main-

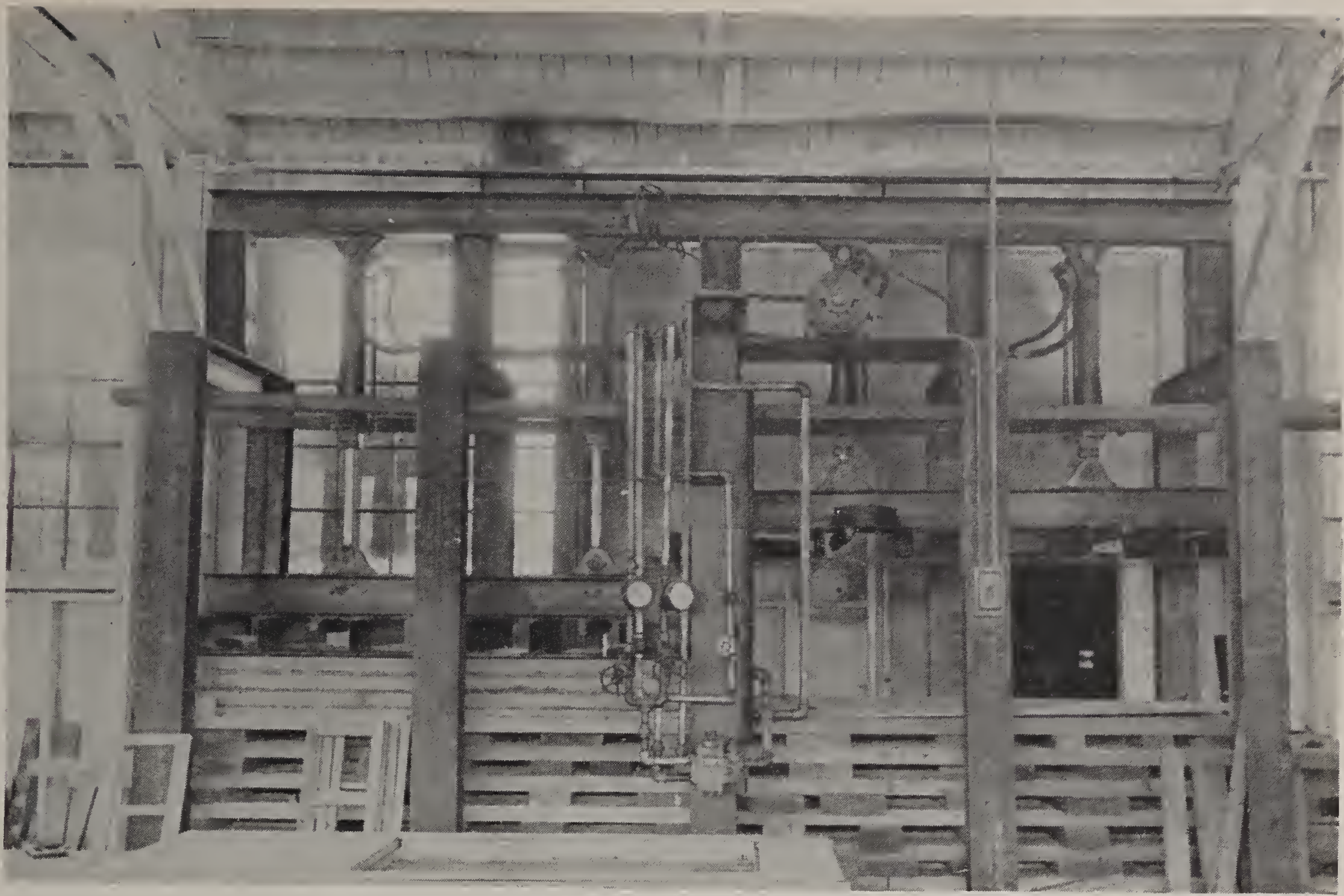


FIGURE 14–61.—Double hydraulic cold press capable of pressing two stacks of 8-foot panels simultaneously.

tain pressure and the bundle is removed from the press into a long heated chamber (fig. 11–8) to speed cure of the glue. The curing chamber accommodates a number of bundles loaded on trucks. As a truck is pushed into the entering door of the chamber another is removed at the opposite end.

Usually complete cure is not attained in the press or curing chamber. Panels should therefore be removed to a storage room until the cure is completed, as discussed in section 14.7.

14.46. Final Machining.—The amount of machining necessary after panels have been assembled varies with the type of construction. Nailed panelized construction requires little, if any. Stressed-cover panels, especially modular panels, are sometimes sized to final width in a double-end tenoner (fig. 10–8) and sanded lightly with a belt sander (fig. 10–11) to remove slight rough spots or other irregularities that may interfere with finishing. Cut-outs for window openings and grooves for connecting panels (fig. 14–63), are also frequently made. None of these machining operations should be undertaken until the glue has been adequately cured. They should, however, be done before panels are finished or toxic-treated.

14.47. Attachment of Trim.—The final assembly operation preceding application of finishes is usually the application of door, window, and other trim. This is, in general, a simple carpentry operation, and includes puttying and other sealing work (fig. 14–64) to assure weathertight joints around wall openings.

14.5. PAINTING OPERATIONS.—A survey of 28 factories making prefabricated housing in the latter part of 1946 disclosed only one in which both interior and exterior woodwork was completely finished at the factory and one other in which interior woodwork was completely finished but exterior woodwork received only a coat of sealer. In 10 factories no finishing of any kind was done; at two others nothing was applied on interior woodwork but on exterior woodwork either a water-repellent preservative or a sealer was applied. In two factories, both interior and exterior woodwork received a sealer and a coat of priming paint, leaving one

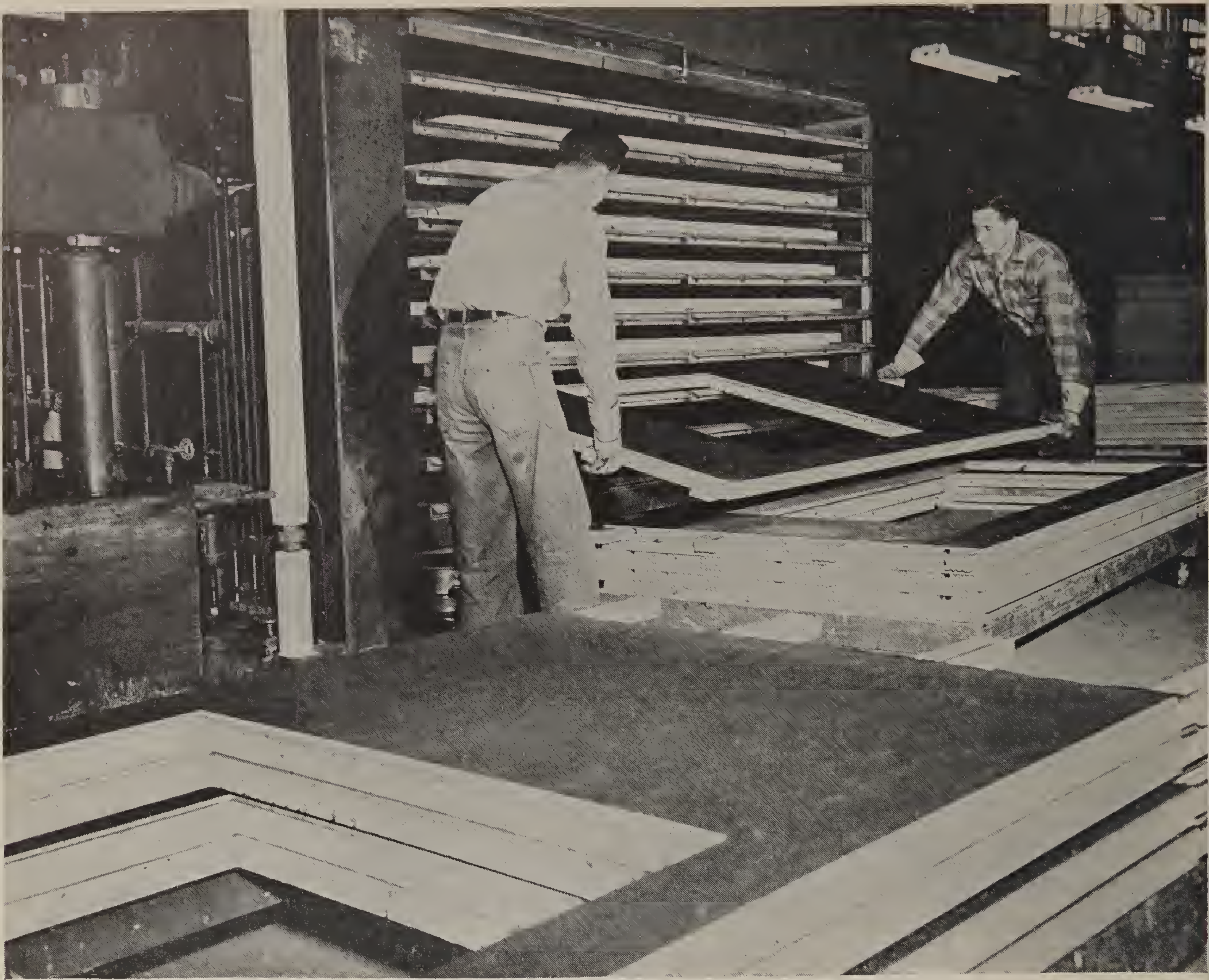


FIGURE 14–62.—Multiple-opening hot press with capacity of 10 panels. Note resin-treated paper finish on panel surfaces.

coat of finish paint to be applied at the site. In another, exterior woodwork received a water-repellent preservative and a coat of priming paint and interior woodwork received the water-repellent preservative. One coat of priming paint was applied to exterior and interior woodwork at seven factories. At two factories wood sealer and at two others water-repellent preservative was applied to both interior and exterior woodwork. On the whole, therefore, painting is left largely to be done at the site after erection has been completed. The reasons for so doing are discussed in section 7.4.

14.50. Application of Coatings.—The principal methods of applying coatings are rolling, dipping, flooding, spraying, and brushing.

14.500. Rolling.—Coatings can be applied on flat surfaces by means of rollers. For factory operations a machine similar to a glue spreader is used; flat panels are passed between rotating rollers one or both of which are bathed in the material to be spread. Plywood manufacturers have used the roller-coating method for applying wood sealer prior to shipment from the plywood factory. None of the prefabricators of housing surveyed was using the method. The method is limited to flat surfaces uncomplicated by moldings or grooves.

Rollers suitable for operation by hand have gained considerable acceptance during the period of shortage of paint brushes. They may be somewhat faster than brushes for painting

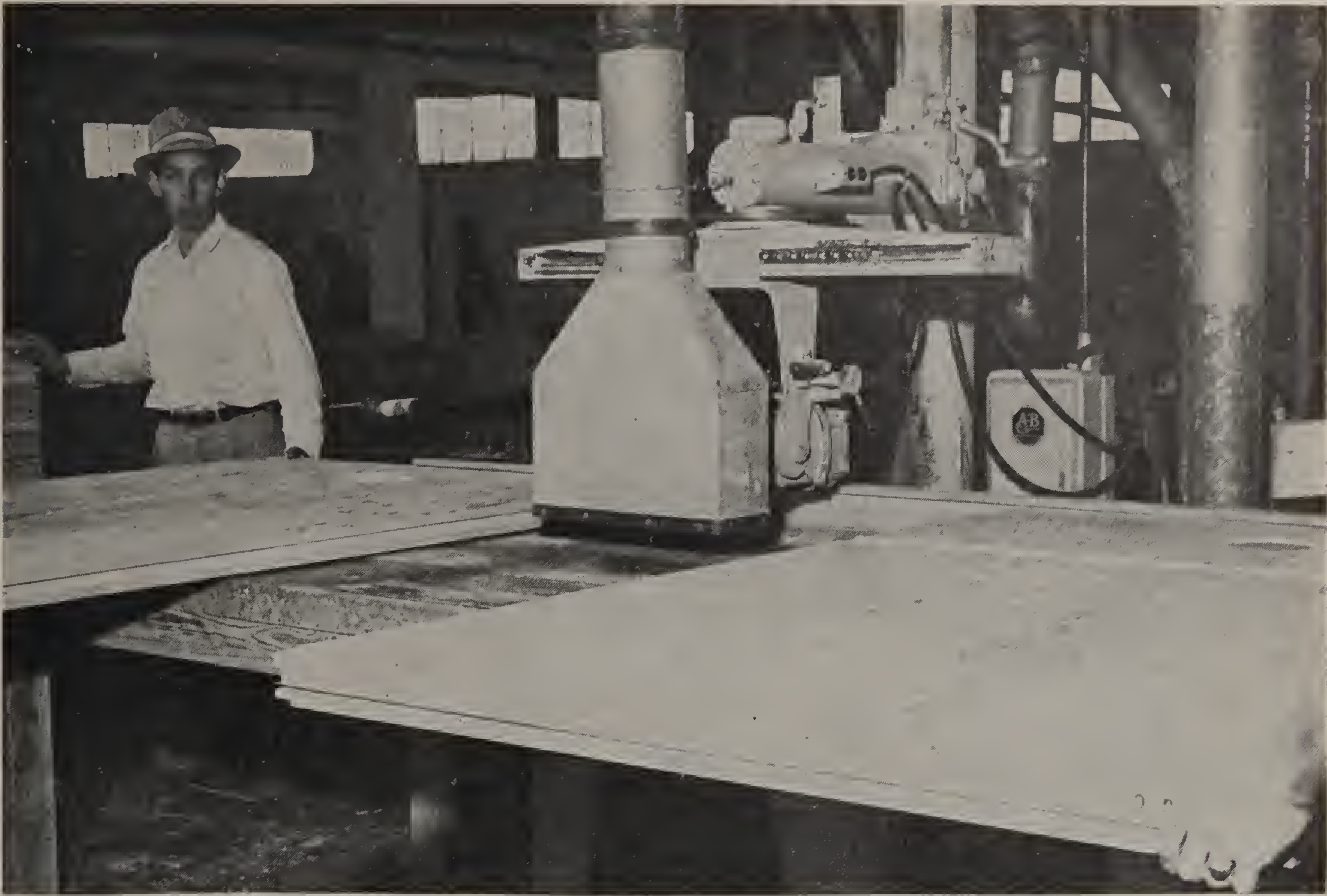


FIGURE 14–63.—Grooving a stressed-cover panel for a special fitting operation at the building site.

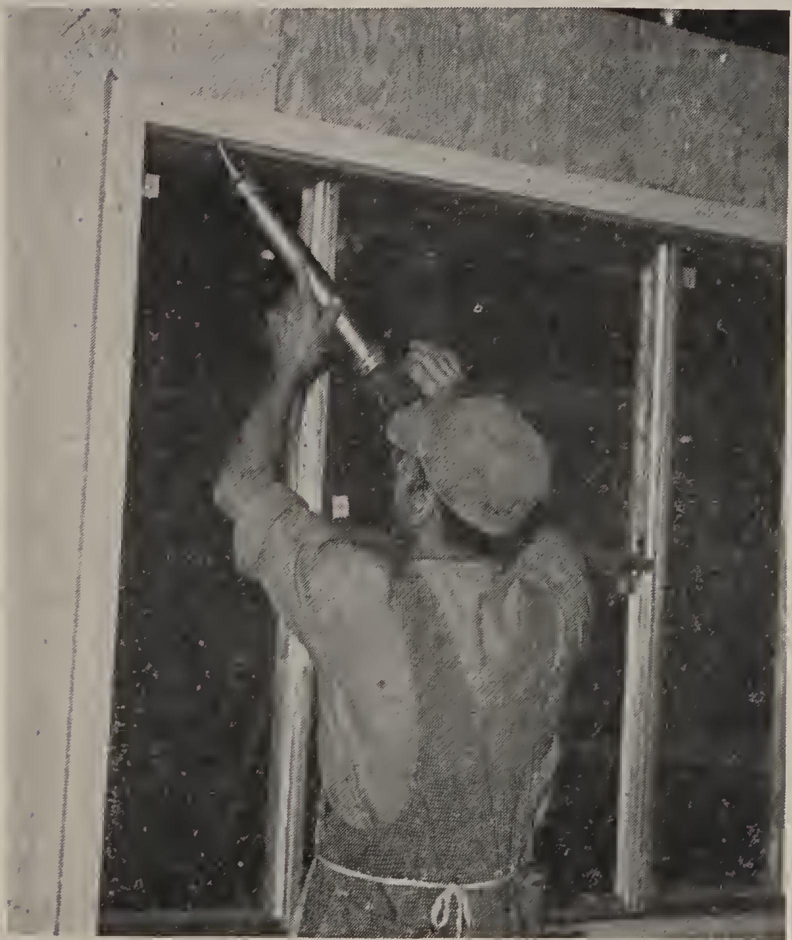


FIGURE 14–64.—Applying putty around a window frame in a stressed-cover panel.

walls and ceilings at the site but they are unsuitable for trim, sash, doors, and moldings. A sharp line cannot be "cut in" with a hand roller. For that reason they must be supplemented with brushes.

14.501. Dipping.—Figure 14–65 shows a dip tank and drain rack for applying wood sealer to prefabricated panels. Panels are immersed in sealer in the tank, then removed and placed on the drain rack for excess sealer to drip off and run back into the tank. If the sealer is absorbed promptly by the wood, the panels may be close piled soon afterward if desired.

Dipping is widely practiced for applying sealers and water repellents, products that sink into the surface of wood. Products containing pigments, such as priming paints, may also be applied by dipping but additional precautions are necessary. The dip tank must be equipped with stirrers or agitators to keep the pigments in suspension, and great care must be taken to see that excess paint drains smoothly over the surfaces, leaving no thick patches. A thick bead

FIGURE 14–65.—A dip tank and drain rack for applying wood sealer or water-repellent preservative on all surfaces of prefabricated panels. Dip tanks can also be designed for a higher degree of mechanization in which panels or parts on a continuous conveyor are dipped and withdrawn without handling.

of paint at the edge from which the excess drips must usually be removed by a stroke of a brush after draining has ceased but before the paint dries. Since paint leaves a coating over the surface, the panels after dipping must be protected from any contact that might disturb the wet paint on the important surfaces until the paint has dried. These extra precautions become more difficult to observe with each succeeding coating. In addition, unless panels receiving topcoats can be withdrawn from the dip tank at a uniform speed equal to the rate at which the paint drains, the coating is apt to be too thin near the top and too thick near the bottom of the panel. Dipping, therefore, is likely to be found unsuitable for applying topcoats in prefabricated houses.

Dip tanks must hold relatively large volumes of coating material. General practice is to add fresh material as needed to keep the proper level in the tank and to leave the tank filled when not in use. There is, of course, constant loss of volatile thinners by evaporation from the tank, and there is constant absorption of oxygen from the air, especially in view of the slow draining of excess material from each panel dipped. When tanks are not in actual use, they should be kept tightly covered to minimize evaporation and oxidation. Even so, the material in the dip tank should be tested at regular intervals, thinner added when necessary to replace that lost, and unduly oxidized material removed and replaced with fresh. The seller of the coating material usually assists in keeping the material in the dip tank in proper condition.

When the dipping method is used, the same material is necessarily applied to all sides of

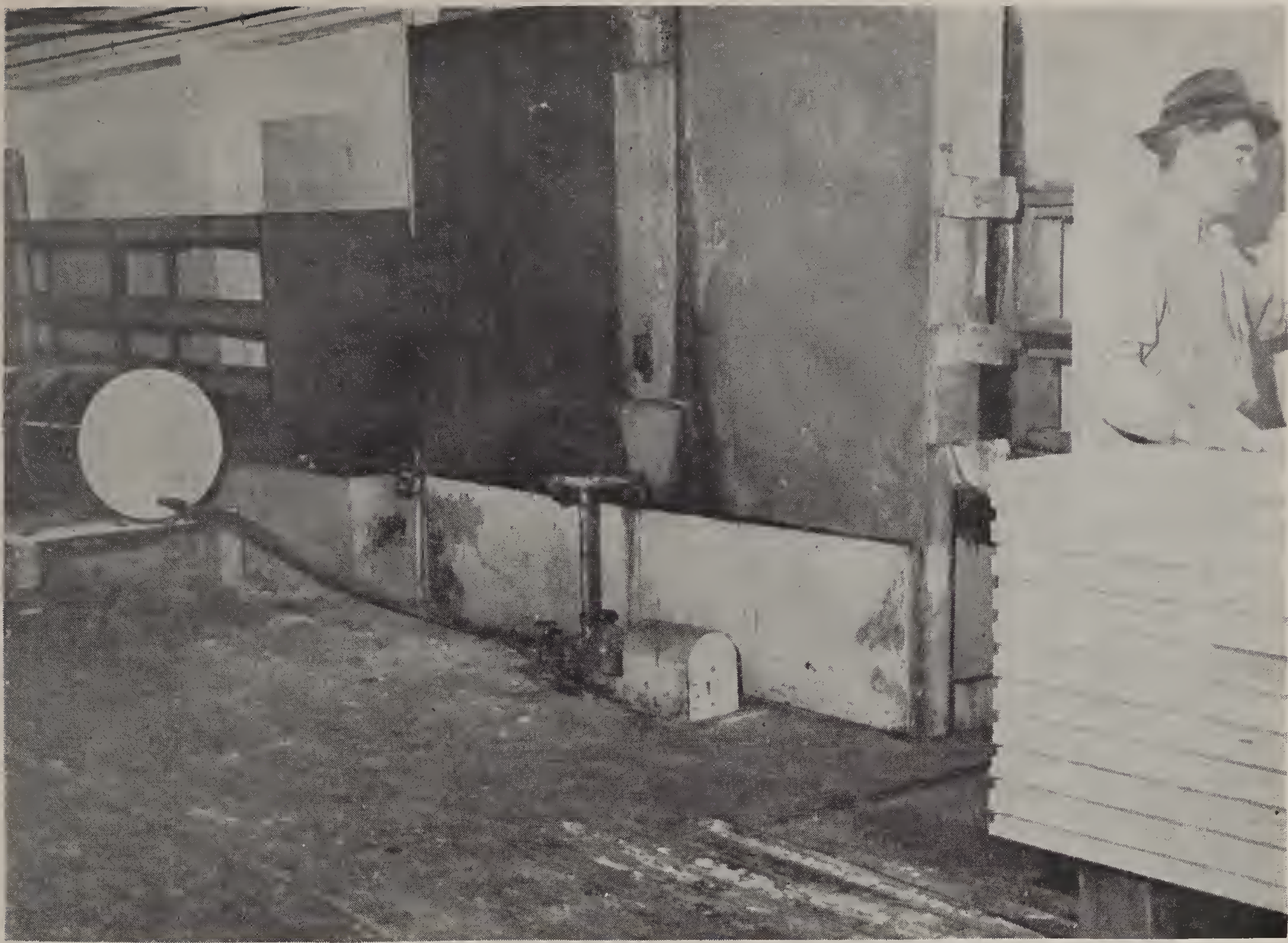


FIGURE 14–66.—Equipment for application of wood sealer or water-repellent preservative by flooding. Panels at the right are hung on an overhead conveyor which takes them through a narrow chamber in which the material is poured over one or both sides of the panels to run down and drip into the drain tank set in the floor. Coating material is circulated by the pump at the floor level (center) and fresh material is supplied automatically from the drum at the left.

the panels. Since interior and exterior surfaces in houses generally require different kinds of coatings (sec. 7.5), this characteristic of the method imposes a further limitation to its usefulness for prefabricated houses.

14.502. Flooding.—Much of the economy of the dipping method without the necessity of applying the same material to both sides of the panel can be obtained by the method of flooding, which is illustrated in figure 14–66. Panels hung from an overhead conveyor pass through a narrow chamber in which coating material is poured in abundant quantity along the top of the side or sides to be coated and drains down over the surface; the excess drips from the bottom edge of the panel to be caught in a drain trough from which it is recirculated by the pump shown at floor level in the picture. The hose from the drum of material keeps the liquid at the proper level in the drain trough.

Except for the freedom to apply material to the desired side of the panels only, flooding is subject to essentially the same precautions and limitations that apply to dipping.

14.503. Spraying. — The most versatile high-speed method of applying coatings is spraying. Good spraying requires highly skilled workmen capable of gaging the amount of paint applied by a nice sense of timing together with knowledge of the equipment and its adjustment. The ability to feel the flow of the paint by which brushing is largely guided is lacking in spraying. Vision is often particularly misleading in spraying because many modern paints should be applied in coatings considerably thicker than is necessary merely to hide the underlying sur-

FIGURE 14–67.—Operator spraying prefabricated panel with wood sealer in a spray booth. Air is exhausted around baffles in the rear wall of the booth, carrying over-spray mist with it. The operator is holding the spray gun in approximately the correct position for coating the edge of the panel toward which the gun is directed. If sufficient air sweeps through the booth and the work always stands between the operator and the outlets for air, it may be safe for the operator to go without the protection of a mask.

face. Inadequately trained spray men tend to apply too little paint for good durability. Some prefabricated houses erected during the war emergency, painted by spraying at the factory, were found to have exterior coatings less than 2 mils thick which deteriorated badly within 2 years. Coatings of house paint should be 4.5 to 5 mils thick (sec. 7.501).

Spraying equipment and spray booths in many states must comply with rules of the State Industrial Commission to guard against hazards of fire and health. Figures 14–67, 14–68, and 14–69 show three different styles of spray booths arranged for conveyorized operations. The first, in which housing panels are hung with the long dimension horizontal and air is drawn straight through the booth, provides the best working conditions. There is little chance for spray mist to reach the operator's face; he can avoid the discomfort of a mask. He can cover all parts of the work without stooping or bending his knees, and the long sweeps of the gun are horizontal. In the second and third pictures the spray operator must reach above his head to coat the tops and bend low to coat the bottoms of panels; instead he is tempted to "arc" the gun badly as demonstrated by the nearer operator in figure 14–69. For proper spraying, the barrel of the gun should always be held on a line normal to the surface being coated.

Modern spray guns in the hands of skilled operators are tools of great flexibility, controlling the fan of atomized paint emerging from the gun very closely. They cannot, however, draw the edge of the coating to a sharp, precise line as can be done with a brush. Spraying, therefore, is most economical when trim and body are painted in the same color. If the trim is to be painted in contrasting color, the line of separation can be marked off with screens and masking tape, but it will often be found just as economical to cut in the trim color by brushing. Glazed sash are best painted by brushing but a cheaper and generally satisfactory way, at least for work at a factory, is to cover the glass with grease, let the overspray fall on the greased glass, and, when the paint has dried, cut the film with a putty knife at the junction of putty with glass and scrape the dried paint from the glass.

Exterior painting at the site is technically practical with portable spraying equipment. Operators should wear masks because of the lack of a controlled exhaust as in a well-designed spray booth. When houses stand close together, care must be taken on windy days to see that neighboring houses are not spotted with overspray.

14.504. Brushing. — Brushing remains the one tool with which almost every operation of coating can be done. Paint can be drawn to a precise line with a brush more rapidly than with any other tool. On surfaces that are not smooth enough for the mirror-like surface of true enamel, brush marks left in good paints by a paint brush provide a surface texture more generally acceptable and more effective in distracting attention from raised grain or other blemishes than the marks left by any other tool. In addition to the brush marks themselves, the patterns formed by the direction of last sweeping of the brush add to the attractiveness if the work is done well. On long, narrow pieces such as trim, the final brushsweeps are always

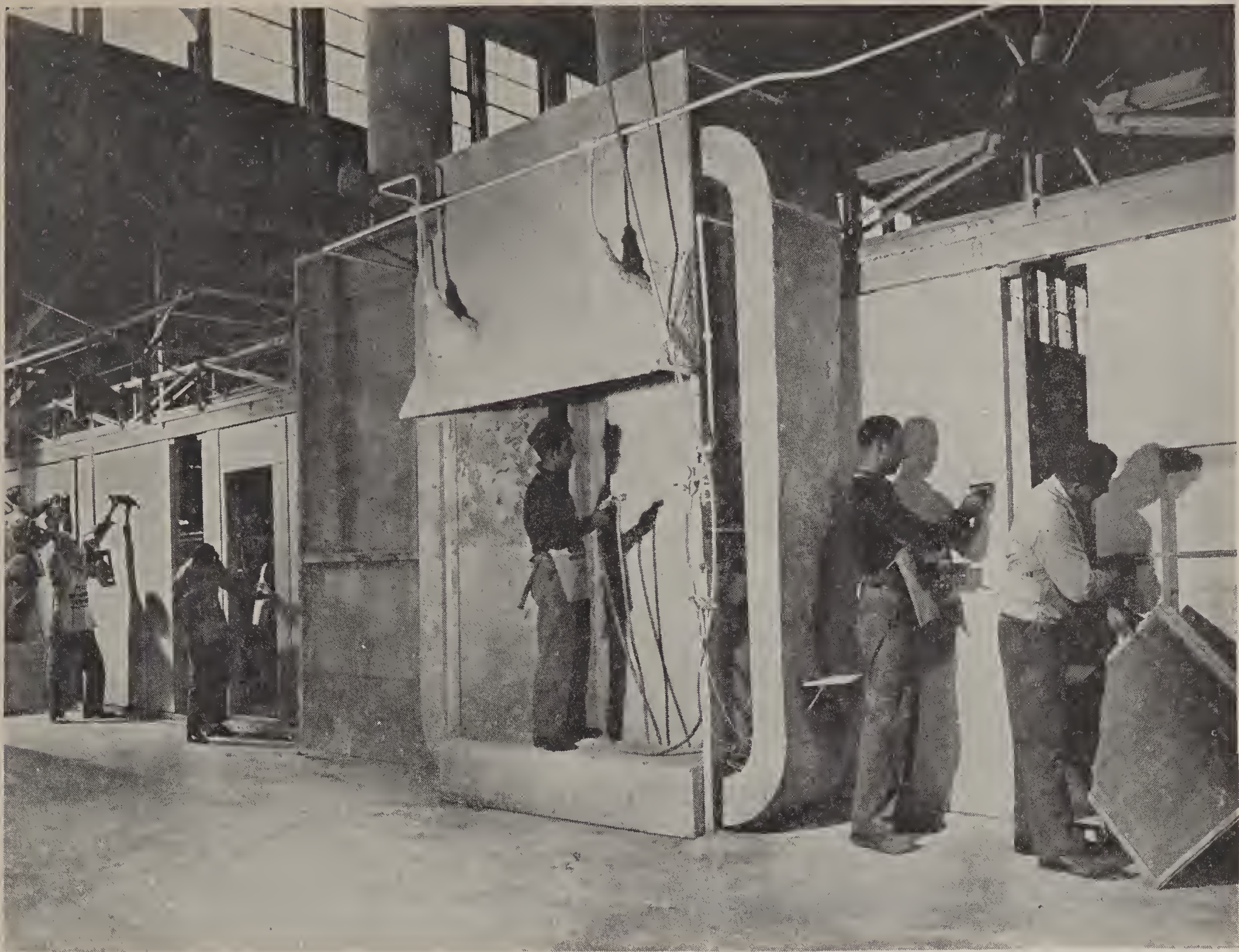


FIGURE 14–68.—Two-spray booths, one on each side of a conveyorized production line for making prefabricated panels. The spray operator must reach uncmofortably high for the tops and stoop low for the bottoms of panels. Mist-laden air is exhausted around the entire periphery of the panels and drawn off finally through the stacks above the booths.

in the lengthwise direction. On large areas, such as sidewalls and ceiling, the last brush strokes usually should be in more or less haphazard arcs.

14.51. Forced Drying.—The rate at which paints dry increases as the temperature is raised. On wood, the extent to which advantage can be taken of that fact is limited by the temperatures to which wood can be heated without damage, the loss in moisture content of wood in hot, dry atmospheres, and the expansion of the air within the wood beneath the coating. The baking temperatures often used in coating metal are impracticable on wood. Heating by infra red radiation, now widely practiced on metal, has seldom proved suitable for wood, because rapid expansion of air within the wood blisters the coating. If not heated too rapidly, however, drying of coatings on wood can be greatly hastened at temperatures up to 140° or 145° F. without damage to either wood or coating (fig. 14–70).

Since the relative humidity of air is decreased on raising its temperature and wood dries out in warm, dry air, it is usually advisable to humidify the air in forced drying rooms to 40 to 45 percent by introducing water vapor with the warm air. That is still insufficient relative humidity to maintain wood at 10 percent moisture content but, if much higher relative humidity prevails in the drying room, wood brought in from a workshop at 70° F. will, until it has had time to become warm, be below the dewpoint; moisture may condense on the

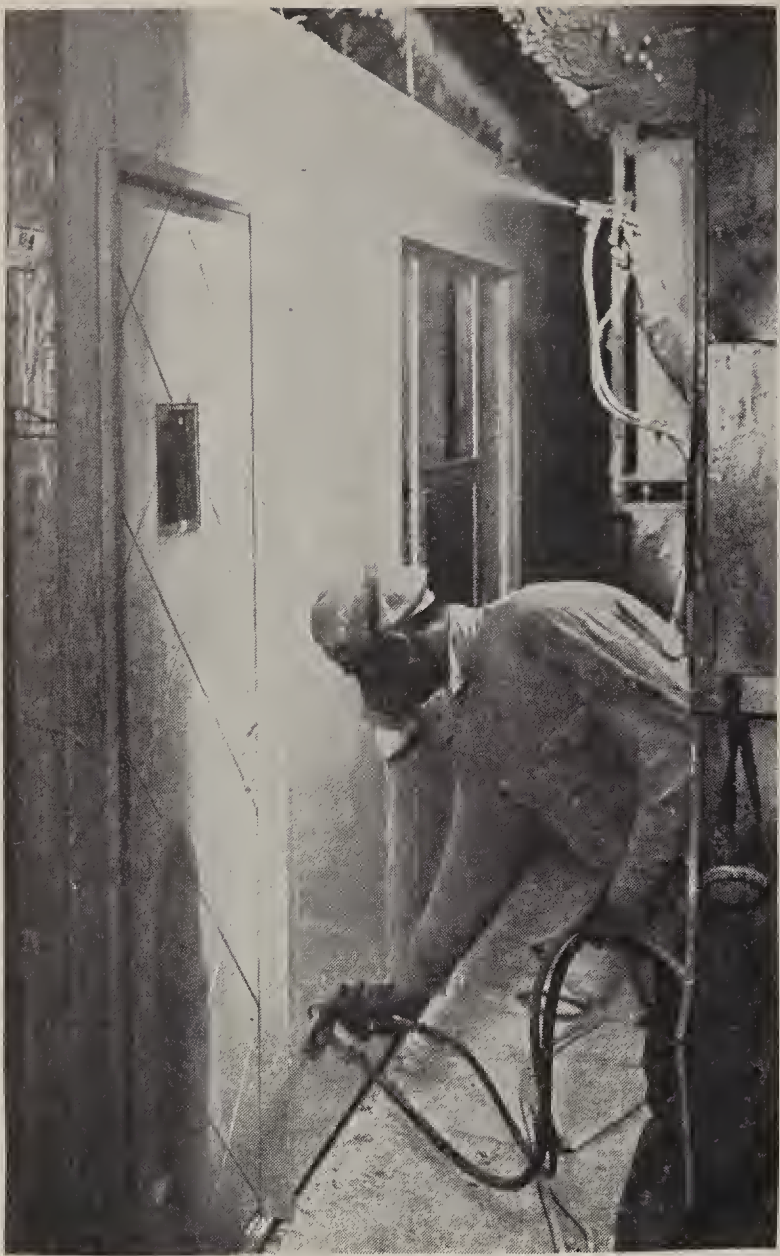


FIGURE 14–69.—Two operators spraying paint in a spray booth. Air is exhausted through the opening at the top of the booth. The operator must wear a mask because his head is sometimes between the spray gun and the exhaust. The nearby operator is "arcing" his gun badly to avoid the discomfort of bending his knees as much as is necessary to spray the bottom of the door properly.

painted surface and damage the coating by dulling its gloss or, if condensation is severe enough, roughen or wrinkle the coating. On panels consisting of relatively thin skins on thicker structural framework, the areas over the structural members take longer to warm up and may be more severely affected by condensation than the unsupported or well-insulated areas between, producing a checkerboard marking of the dried coating disclosing the framework underneath. Ordinarily there are no such troubles when the panels entering the drying room are not below 70° F. and the room is kept at no more than 145° F. at 40 to 45 percent relative humidity.

14.52. Wallpapers and Other Coverings. — Plywood walls and ceilings may be covered with wallpaper or other materials instead of painting or otherwise finishing them with coatings. Papering must be done at the site after erection of houses made of prefabricated panels unless it is permissible to let the joints between panels show.

To make certain that raised grain in the plywood will not show through wallpaper, some prefabricators apply an inexpensive backing paper or fabric and then apply the wallpaper over it. Even when so supported, however, care must be taken to see that all joints between panels are made firm enough to prevent much movement at the joints under paper during the seasonal changes in moisture content of the woodwork. Any appreciable movement at the joints will either rumple or break the wallpaper over them in an unsightly manner.

The better types of modern wallpapers are washable. Such papers have been lacquered or otherwise coated so that they can be cleaned by careful washing after they have become soiled. Only dirt of a solid nature, such as dust and soot, can be removed by washing; grease or dirty liquids penetrate too deeply to be washed off. There are, however, thin kinds of oilcloth made for wall coverings to be applied like wallpaper which do not allow greases or liquid stains to penetrate and withstand vigorous washing. Such wall coverings are usually semiglossy or glossy in luster; they are suitable for bathrooms and kitchens but less acceptable for living rooms and bedrooms.

Where cost permits, there are wall coverings consisting of very thin hardwood veneers of luxurious appearance made flexible by special treatment and mounted on fabric for hanging on walls like wallpaper. The final effect is that of expensive panelled woodwork.

14.6. INSPECTION FOR QUALITY CONTROL.

14.60. General. — Inspection does not create quality; it does, however, help to insure that quality will not fall, for any reason, below the standards called for by the design. Hence, inspection is essential to the satisfactory service of the product by its users and can contribute greatly to the reduction of waste. A defective stud, for example, is much less expensive to eliminate at the cut-off saw or jig than after it is in a panel.

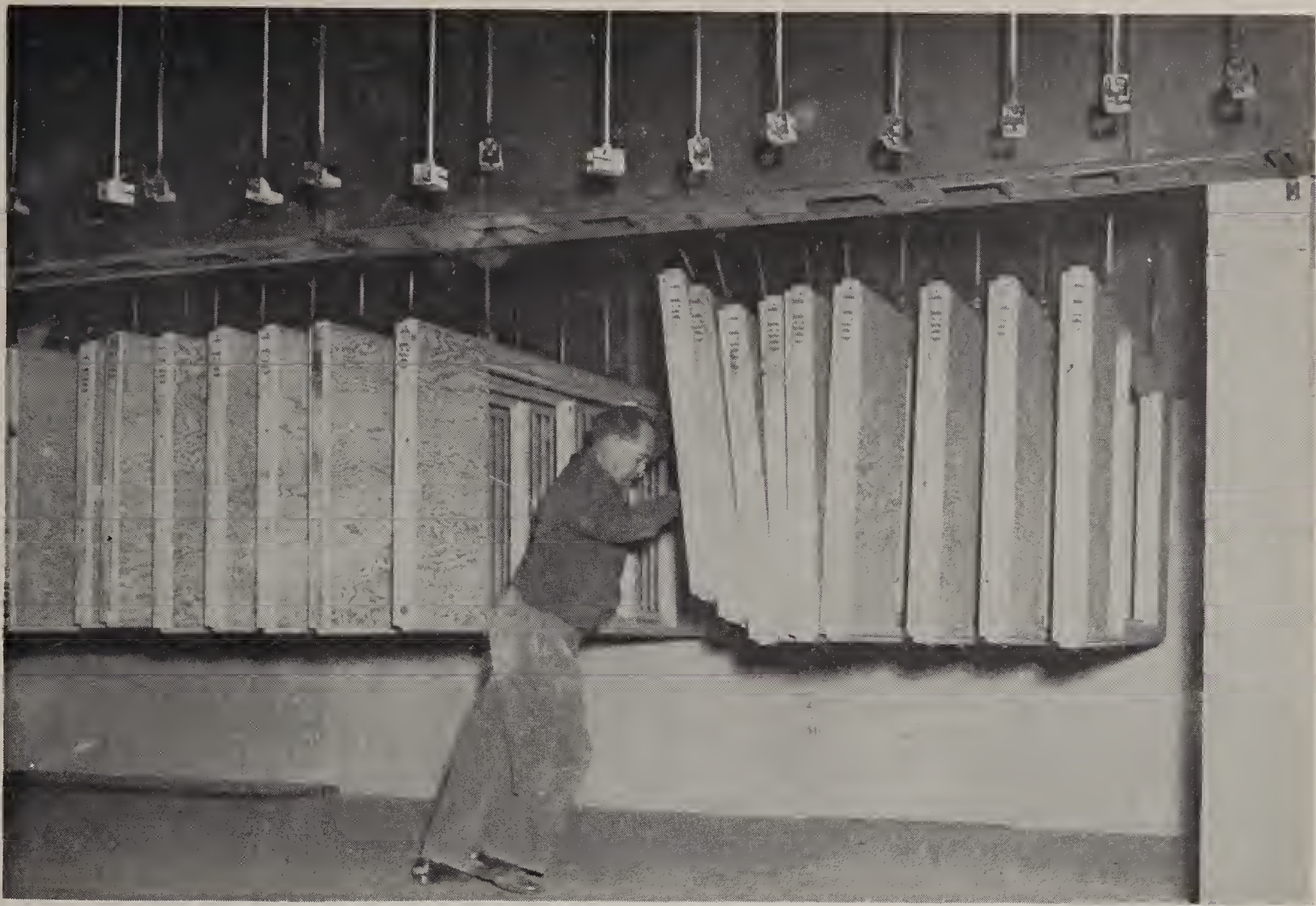


FIGURE 14–70.—A room for forced drying of coatings on prefabricated panels. The panels are suspended from hangers. The air in the room is kept approximately at 140° F. by warm air circulated by a blower.

Inspection practice and organization varies with the size of the plant, from small factories where every workman is expected to do his own inspection to large mass-production operations where special staffs of inspectors check every step in manufacture from the raw material to the assembled house. In large plants, inspection includes (1) raw materials, (2) processing of parts, and (3) assembled products. Often the manufacturer also maintains a service inspection department to handle complaints from purchasers, study performance of the houses in use, and conduct long-time tests at the factory of different panel constructions and their component materials as well as complete houses.

14.61. Inspection of Raw Materials.—Inspection of lumber for physical defects is generally made when the lumber is received for initial sorting and cutting up into framing members, trim, and other components. Inspection at this point may virtually constitute regrading on the basis of defects permitted for different components.

Such regrading is done in connection with cut-off and resawing operations, either by the workmen doing the actual sawing (fig. 14–71) or by an inspector who sorts and marks pieces according to the parts for which they are considered suitable. Common defects usually forming the basis of such inspection are discussed in sections 2.3 and 4.1. Inspection is usually necessary at this stage to select such critical components as framing members for stressed-skin panels (sec. 14.30). Manufacturing and seasoning defects, such as warp and wane, are also guarded against at this stage of manufacture.

At the time lumber is received, it is generally also inspected for moisture content as discussed in sections 3.6 and 9.2.

Inspection of plywood is not so critical if it is purchased on the basis of grades for specific uses (secs. 4.1 and 12.1). All shipments, however, should be examined to see whether they check as to grades and sizes with the materials

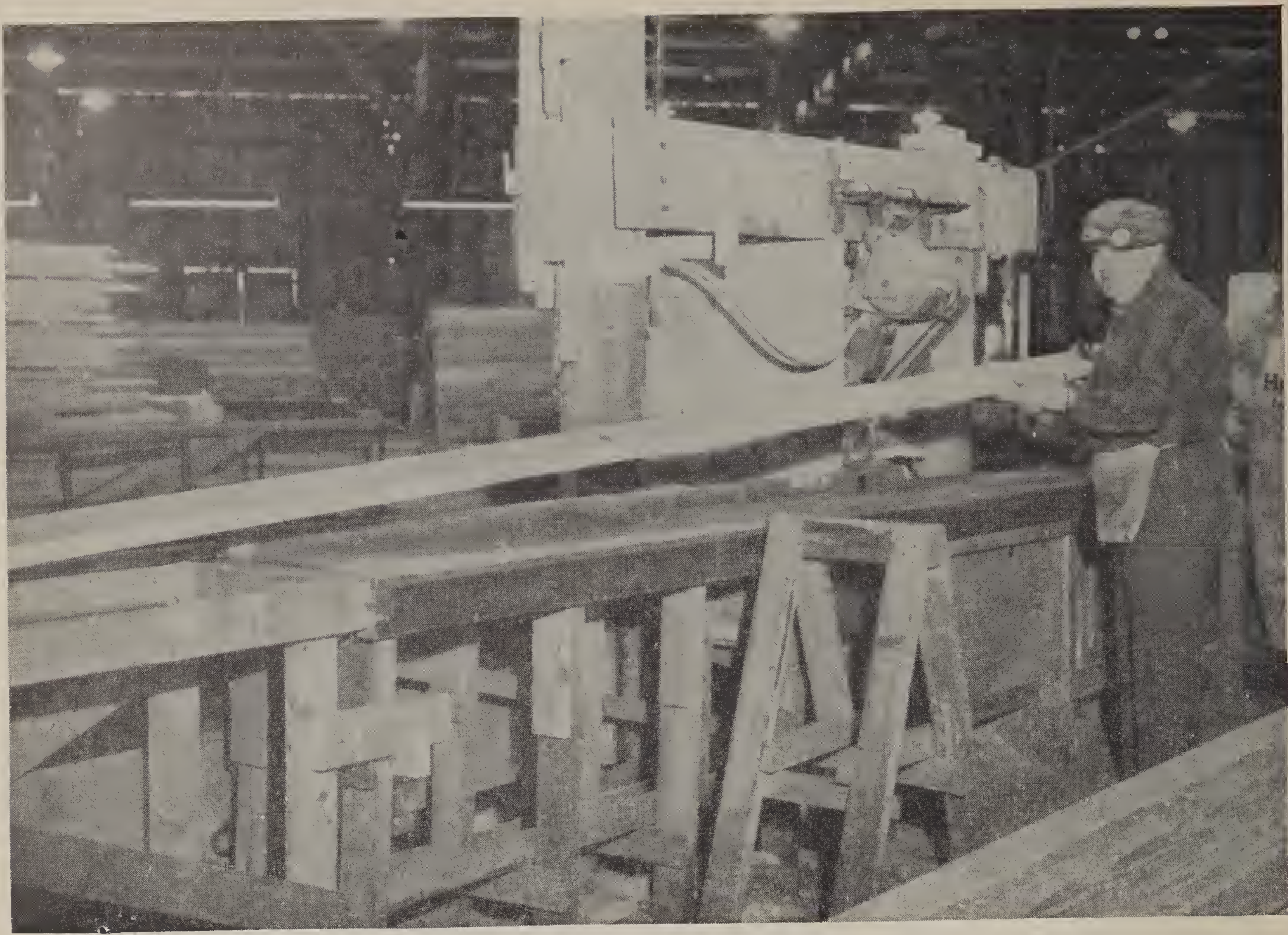


FIGURE 14–71.—Workman inspecting framing lumber for defects before cutting it to length.

ordered. Moisture content tests of moisture-resistant plywood are also advisable, especially if the plywood is to be used in connection with high-frequency dielectric equipment (sec. 11.372).

Inspection of such materials as fiberboards and insulation is usually limited to examination for damage in shipment. When a new material is considered for use, it may be subjected to preliminary tests to compare its efficiency with that of other comparable materials previously used. Such tests, however, are generally the province of the design department rather than that of the inspection staff.

14.62. Manufacturing Inspection.—Inspection during manufacture embraces such important points as (1) accuracy of dimensions, (2) workmanship, and (3) quality control of such materials as glues and finishes.

While no rules can be set down governing the frequency of inspections during processing, in general the frequency should be sufficient to insure that the conditions of manufacture remain correct. Experience will indicate how frequent such inspection should be. Where operations are by automatic machines, occasional check for dimensions will insure that, so long as the checks reveal close adherence to tolerances, adequate accuracy is being maintained. Manual operations, on the other hand, depend upon the reliability of the operators; inspectors should study the workmanship of each operator and pace their inspection of his work accordingly.

14.620. Dimensional Accuracy. — Inspection for dimensional accuracy should be directed primarily to parts involving critical joints. Among such parts are framing members of stressed-cover panels; the joints between panels; panel width and height; grooves for insertion of splines, insulation, or other parts; and bolt holes, bracing gains, and similar cutting work

that will be of critical importance during assembly and in the serviceability of the finished product.

Such dimensions are generally dependent upon the maintenance of machine adjustments and sharpness of cutting blades. Even a slight error in thickness of a framing member, for example, may interfere with proper gluing of the skin to the frame, leaving a gap in the glue line at which stresses will concentrate in service and possibly cause early failure of the part. Again, unless panel joints mate properly at the building site, workmen tend to force them together willynilly, shattering edges or leaving unsightly seams; inspection should insure that tolerances are maintained that will give a tight joint without interfering unduly with assembly. Machines should be checked regularly for accuracy of tooth or blade alinement and sharpened as often as necessary. The effects of dull cutting equipment quickly become noticeable on a fibrous material like wood, leaving telltale marks on smoothed surfaces, chipped, raised, or fuzzy grain, mashed fibers in holes, and similar indications of substandard machining.

Standard measuring instruments are usually accurate enough for dimension inspection. A variety of functional devices is available, among them thickness gages and gage blocks, calipers, bevel protractors, combination squares, and various combinations of these instruments devised for rapid inspection.

14.621. Workmanship.—Inspection of workmanship involves to a great extent close observation of the reliability of the workman. To do this efficiently, the inspector should be familiar with the operational problems involving the machines used. For example, he should know the most suitable operating speeds, rates of feed, and other factors involving good workmanship with woodworking equipment, in order that causes of imperfect production can be quickly traced. Even though the inspector has no direct control of production conditions, he is in a position to assist materially in reduction of waste if he understands the mechanical conditions that lead to rejectionable work. Such understanding will also assist him in detecting more quickly actual instances of carelessness. While it is not always the inspector's responsibility to judge the capacity of workmen for their duties, in the smaller plants particularly he may also be the foreman on the job.

14.622. Gluing Inspection. — The vital importance of good gluing technique necessitates close inspection of (1) the quality and preparation of the glues used, (2) techniques of application and assembly of parts, (3) testing of glue joints for quality, and (4) inspection of such equipment as mixers, spreaders, and presses.

In checking the preparation of glues, the inspector should ascertain that the manufacturer's directions are followed as to mixing of hardener, catalyst, extender, and other ingredients in proper proportions. The proportions of the components should be determined by weight rather than by measure or by guess. The weighing devices should be of suitable sensitivity and they should be inspected frequently to insure suitable mechanical maintenance and cleanliness. Mixing equipment should also be examined periodically to see that it is maintained in clean condition to avoid contamination of glue. It should be the inspector's responsibility to see that working life of the glue used is not exceeded and that workmen do not add water or other thinning agents to keep glues at usable consistency beyond their working life.

The inspector should be thoroughly familiar with all gluing techniques and processes used in the plant. Of especial importance is an adequate and evenly distributed gluing pressure. Devices and methods for applying gluing pressure should be examined critically to insure that the gluing pressure is within the range recommended and that it is evenly distributed over the joint area.

Also of importance is a close check on glue spreading. Where roll-type spreaders are used, poor spreading is less likely to occur than when brush, glue gun, or other means are employed (fig. 14–72). Assembly of frameworks and jigs should also be inspected to assure that true joints are produced between framing members; inaccurate assembly on the jig can cause members to be out of plane, thus interfering with intimate contact between mating surfaces of frames and skins. The interval between spreading and pressing should be limited according to the type of glue used (sec. 11.35). Permissible

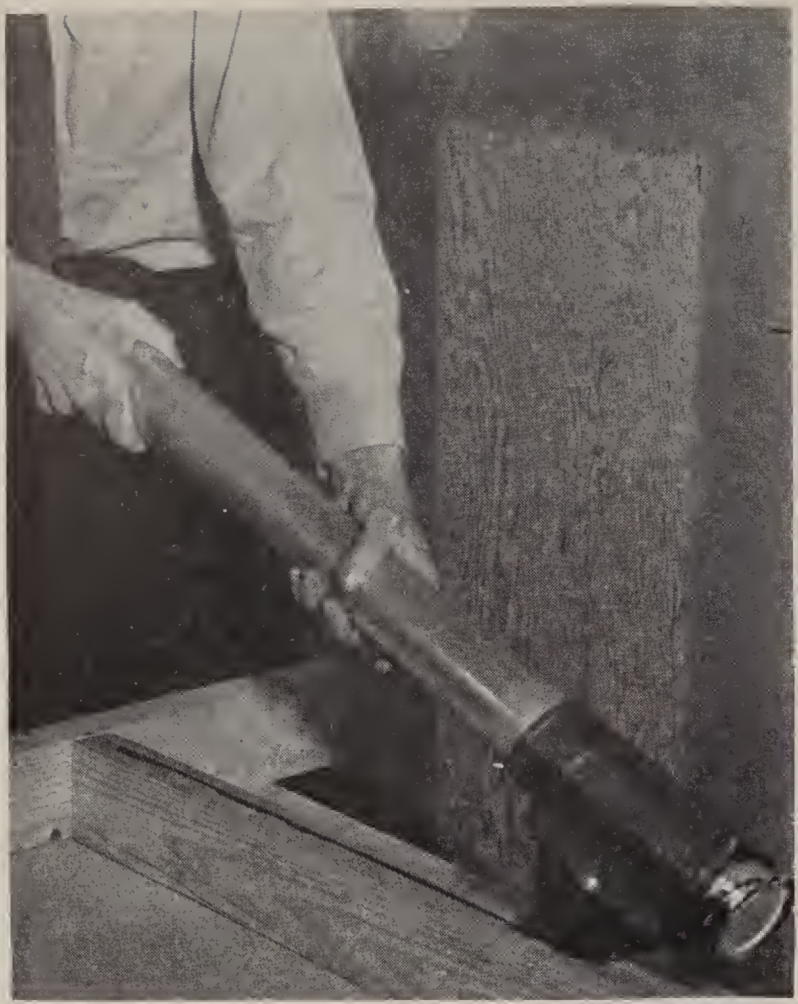


FIGURE 14–72.—Tilted head of glue gun and resulting inadequate spread of glue.

assembly periods are somewhat more likely to be exceeded in nail-gluing operations than in operations employing hydraulic presses.

Glue joint quality tests are of the block-shear type between solid wood members or between solid wood and plywood, as described in section 11.39. This test method is widely used in woodworking plants and should constitute a part of the inspection routine in prefabricating plants.

A good visual indication of glue-joint quality in the finished part is evidence of glue squeeze-out along the joint edges. Lack of squeeze-out may indicate a dried joint, and excessive squeeze-out may indicate a starved joint. Obvious gaps in joints, where no bond whatever exists, constitute cause for rejection of the part regardless of their size because, when the part is put to use, stresses will concentrate at such points.

All equipment should be inspected periodically to see that it is in good working order. Pressure devices, whether nailing machines, clamps, or presses, also require inspection. Evidence of poor functioning of such equipment includes improperly set or driven nails, excessive nail spacing, and "burns" in parts set in high-frequency equipment. Blocking and cauls used in presses or with clamps should be kept in good condition.

14.623. Insulation and Vapor Barriers.—The efficiency of insulation and vapor barriers largely depends, provided approved and tested products are used, upon proper installation. Of particular importance is the condition of the material when installed; tears especially in vapor barriers, greatly reduce efficiency and should not be permitted. Proper installation is also important. The inspector should be especially careful to see that seams between insulation and framing members are as tight as the method of installation permits and that the insulation is properly positioned with respect to required air spaces and firmly attached so that it will not in time become compacted. Proper installation, of course, also implies that the materials be installed so that they will function as intended (sec. 8.23); vapor barriers, for example, should always be on the warm side of the panel in service.

14.63. Service Inspection. — Service inspection departments that handle complaints of unsatisfactory performance from customers have a two-fold purpose: (1) The satisfaction of the purchaser and, therewith, maintenance of good will; and (2) the opportunity such service affords of studying the performance of their products in use. Linked with the second purpose is a varying amount of service testing at the factory which may be benefited by field observations.

Often such observations reveal difficulties that can be corrected by minor design changes. For example, a window framing detail may under certain conditions of service permit rain water to seep into the panel, eventually building up a decay hazard. A simple change in framing, trim, or caulking practice may remedy this defect and improve the serviceability of all future panels of that design when carried over into the factory. Or a pronounced dirt pattern necessitating repainting every year or two of houses in service may be remedied by a better balance in thermal transmission properties of insulation and panel framing (sec. 8.1).

Inspectors sent into the field as trouble shooters of this sort must be familiar not only with

the structural details of the houses they inspect but must have a sound basic knowledge of the causes of service difficulties. A service testing laboratory at the plant affords good training for field inspectors.

14.7. STORAGE AND SHIPMENT OF HOUSE PARTS.—In storing and shipping panels, millwork, and other parts of prefabricated houses, it is necessary to take precautions against the possibility of damage from various causes. The mere fact that the finished house will be exposed to the rigors of weather is not justification for unnecessary exposure of the parts to it beforehand. Some of the parts will not be exposed in the completed house, and even exterior wall panels are given protection in the finished house that they do not have before site assembly. Of particular importance in handling, storage, and shipment is precaution against damage to joints, especially incompletely cured glued joints of panels fresh from the assembly line and panel edges that may be deformed by rough treatment or exposure. Adequate safeguards during storage and shipment can greatly reduce repair and replacement expense at the building site.

14.70. Factory Storage.—Aside from economic considerations, the need for storage of prefabricated house parts depends primarily upon the type of construction. With nailed panelized construction, shipment direct from the assembly line to the building site and prompt erection are technically feasible unless paint or other finish has been applied in the plant, in which case at least an overnight drying period should be allowed (sec. 14.51). With glued construction, however, this is usually not good practice. A period of at least a few days' storage is recommended.

The principal reason for this storage is to permit glue to cure adequately. Whether hot-pressed or otherwise subjected to pressure and heat, glue joints are not usually fully cured before pressure is removed (sec. 11.37). Even nail-glued joints, to which pressure is constantly applied, take several days to cure fully. Meantime, serious damage may be done by rough handling. A secondary purpose of storage is to permit water added to the wood by the glue to distribute itself uniformly (sec. 11.373). If finishing is feasible immediately after the gluing operation, the storage period will be ample for drying of finishes. If further machining operations are necessary, however, they should follow the storage period for cure of glue.

The most convenient method of storage is, of course, to run the conveyor system directly into the warehouse, making it unnecessary to unhook and stack the panels. This method, however, is usually wasteful of storage space and conveyor equipment. Some prefabricators flat pile panels, moving them about in stacks of a half-dozen or more with fork-lift trucks. End racking is also practiced. The type of piling is unimportant as long as the workmen are aware of the need for careful handling.

The warehouse should be maintained at temperature and relative humidity conditions approximating those of the gluing room. Too low a temperature in the warehouse will retard the setting of the glue, prolonging storage unnecessarily. Relative humidity conditions markedly below those of the glue room may cause excessive drying stresses and delamination along the glue lines. Very high relative humidity is not particularly harmful to partially cured glue lines, but may cause parts to pick up moisture and expand, creating subsequent difficulty in joint assembly.

14.71. Shipment of House Parts.—Prefabricated house parts are commonly shipped by truck unless distances are long enough to warrant rail transportation. The need for protection from weather conditions during shipment is discussed in section 9.214. Trucking is generally preferred for distances up to 300 miles because parts can be transported directly from the factory to the building site. Some prefabricators operate on delivery schedules timed to deliver the parts at the building site the morning that the shell is to be erected. Need for site storage facilities is thereby eliminated, since millwork and other interior parts can be stored in the house. Rail transportation necessitates rehandling, trucking to the building site, and often some storage facilities. The choice of transportation medium will usually be governed by the distribution methods of the individual prefabricator.

14.710. Truck Transportation.—Where a fleet of trucks is operated, they can be designed and fitted for safe loading of parts. Two types of loading are used, racking and stacking. Racking

FIGURE 14–73.—Racked panels in a trailer truck. Note cross bracing.

consists of loading panels vertically, the bottom edges seated between blocks permanently fixed to the truck floor (fig. 14–73). Transverse wood strips are nailed to the ends of panels and to wall posts of the truck to keep them from swaying against one another in transit. Skid strips lightly nailed to the edges of panels protect them from damage. These strips are usually attached at the factory when the panels are placed in storage and are not removed until the panels are about to be set in place in the building.

Stacking consists of flat piling. Generally, the load is so planned that a given number of panels, perhaps those for a complete house or those for the exterior walls, and roof, are bundled together with rope or steel strapping at the warehouse and loaded with cranes or lift trucks (fig. 14–44). The object of bundling is to reduce waste of space to the minimum. Cushioning or blocking should be used where strapping passes over edges of panels or millwork to prevent mashing. Some prefabricators fit containers for trim, molding, and similar materials underneath the truck body where clearance permits. With some types of panelized construction, such materials can be strapped or blocked between studs of an open-faced panel or section. Some forms of panelized construction, such as floor and ceiling sections, can be nested in stacking (fig. 14–74) to reduce waste of cubage.

14.711. Rail transportation.—For rail shipment, the same methods of loading, racking or stacking, are used as for truck loading. Generally, however, there is need for more efficient blocking and bracing in boxcars than in trucks, due to rougher handling conditions. The contents of a boxcar are subject to more severe stresses than those of a truck, because railroad cars are jerked and bumped more severely in stopping, starting, and switching during makeup of trains. The practice of "humping," or making up trains by letting them gravitate on a slight

FIGURE 14–74.—Floor panels nested in pairs to reduce waste of cubage in shipment.

downgrade to the proper track in a switchyard, is especially severe upon contents because the cars sometimes attain speeds of 15 miles an hour or more before they ram against the others of a train.

Types, capacities, and sizes of boxcars available for transport are given in the Official Railway Equipment Register. Railroads employ car inspectors for consultation with shippers as to methods of loading and restrictions imposed by the railroads as to height of load, placement of loads in the car for distribution of weight, and other factors. Shipment of panelized construction in open-top cars for long distances is not advisable; flat cars are suitable for shipment of unit assemblies with roofs in place if load-width requirements of the railroad permit. Boxcars generally are available in either side- or end-opening types.

Where parts for a number of houses are to be shipped to a given destination or distribution point for truck transportation to the site, some prefabricators load cars with certain parts for several houses. Thus, one car or part of a car may be loaded with floor panels (fig. 9–11), another with wall panels, and a third with millwork. The stacking or bundling method is then employed.

Panels and other parts may conveniently be rack-loaded if a complete house is being shipped to a certain destination for erection (fig. 14–75). Much the same procedure is used in loading freight cars by this method as in loading trucks, except that blocking and bracing are heavier to counteract end and side movements induced in shipment. Blocking and bracing may involve, in various combinations, floor blocking, side blocking, hold-down cleats, cross-car bracing, crib bracing, bulkheads, and other means of holding the loads in position.

For panelized construction on skids, crosswise floor blocking is extensively used (fig. 14–76). Backup cleats should be long enough to assure adequate strength, preferably 12 inches long. Nominal 2-inch lumber is suitable. Cross bracing is illustrated in figure 14–77 and with diagonal reinforcing in figures 14–78 and 14–79. That shown in figure 14–78 is known as K-bracing, that in figure 14–79 as knee bracing. A variation of K-bracing, with the diagonals anchored to the car walls above the load, is suitable as top bracing for prevention of vertical movement of loads during transit.

Crib bracing (fig. 14–80) is widely used for separating load units at the center of the car. When crib bracing is attached to doorway protection timbers in double-door boxcars, the doorway protection must be strong enough to prevent outward pressure on the auxiliary door post. When insufficient space remains in the doorway to use crib or other bracing, bulkheads (fig. 14–81) may be used.

Variations in these methods of blocking and bracing can be adapted to requirements for side bracing, either against walls or along sides of the load.

14.72. Site Storage of House Parts.—The safest way to escape damage due to site storage of house parts in the open is to avoid it. Builders usually do so by planning their construction schedules well in advance so that, as parts for another house arrive, its foundation and subfloor are in place and the walls and roof can be erected during the space of a single workday. The rest of the house parts are then stored under the roof.

Where it becomes unavoidable, due to weather or other conditions, to stack house parts in the open, every attempt should be made to protect them from damage. The more highly finished parts should be given most protection

FIGURE 14–75.—Rack-loaded boxcar.

by stacking them so that such parts as exterior wall panels protect them. Tarpaulins should be thrown over the completed stack and drawn tight, so that water cannot collect on them in pools. Lumber can be bulk-piled, but should be covered either with rough lumber or a tarpaulin. Rough lumber should be used to make a level surface at least 1 foot above ground, so that no finished parts will be in contact with the ground. If possible, the panels should be stacked with a slope in one direction, so that rain water will run off. In all cases, the panels should be assembled as quickly as possible.

14.8. SITE ASSEMBLY.

14.80. General.—Site-assembly operations consist in general of (1) foundation; (2) erection of wall, ceiling, and roof panels, together with interior partitions; (3) all interior and exterior finish; (4) application of roofing; (5) installation of electrical, plumbing, heating, and other fixtures; and (6) painting and other finishing. The scope of these tasks is, of course, determined by the amount of work done in the factory.

14.81. Foundation Construction.—Requisites of a good foundation are: (1) Adequate footings and walls to carry the loads of the superstructure without appreciable settling; (2) provision for ventilation; and (3) proper design to prevent surface moisture from collecting under the building.

Foundation and other aspects of the building site that must be considered to assure reasonable permanence of dwellings are discussed in section 6.1. The principal causes of trouble in houses due to inadequate foundations are settling, decay, and termites. Foundations should be so designed as to minimize these hazards, as explained in section 6.1. Additional information

on decay and insects is given in sections 2.39 and 3.8.

Foundation construction for prefabricated houses differs in no important respect from that for comparable conventional houses. The materials and building methods are the same, and design dimensions, such as thickness of walls and width of footings, are frequently prescribed by local building codes.

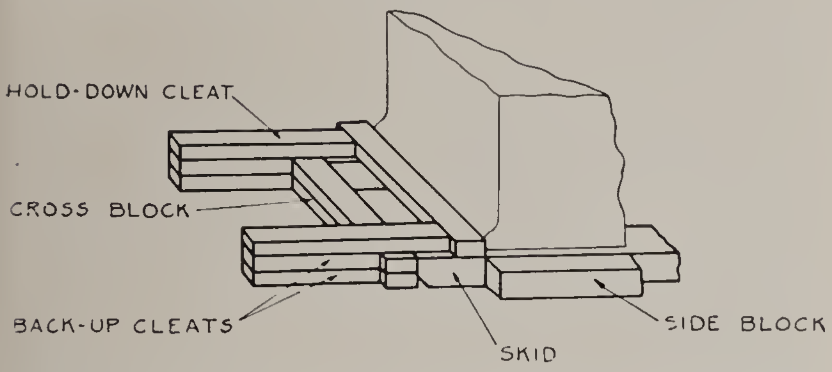


FIGURE 14–76.—End and side blocking of load on skids.

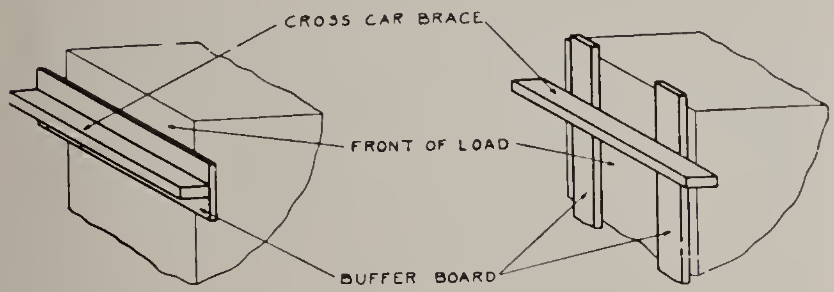


FIGURE 14–77.—Cross-car bracing with vertical or horizontal buffers for protection of load. Buffers guard against mashing of contents.

14.82. Subfloor Construction.—Subfloor Constructions for prefabricated housing cover the full range from conventional joist-and-header construction to stressed-cover panels that incorporate all framing, and require only widely spaced girders and posts for support. Several types of panelized subfloors utilizing joists and headers in conventional sizes are shown in figure 14–6. Girders set on posts for support of panelized floorings are shown in figure 14–15 and a type of panelized subfloor in figure 14–16.

Posts supporting girders should be raised above the ground or basement floor level on truncated pyramidal footings of concrete, as shown in figure 14–18, to provide drainage for moisture that could otherwise result in decay. Where termite hazards exist, posts, girders, and joists should also be pressure treated with a good preservative (sec. 6.1). In some areas, local ordinances require preservative treatment of these members. Girders should also be protected from moisture with asphalt paper at points where they bear on concrete foundations. Foundation openings for girders should be large enough to permit ventilation at the sides and ends of the girder. Usually a sill is placed around the perimeter of the foundation wall. Due to irregularities in the top of the concrete foundation wall, it may be necessary to shim the sill to true level and subsequently to fill the space between the sill and concrete wall with a cement grout.

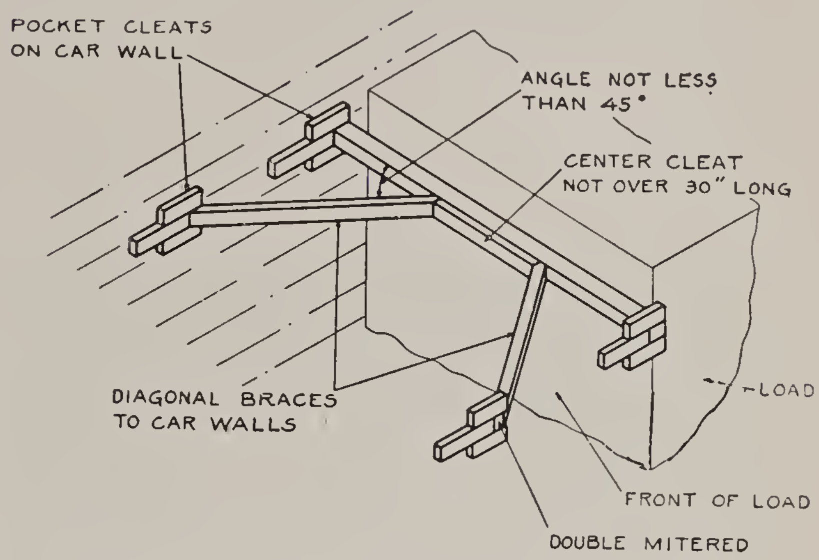


FIGURE 14–78.—K-brace for cross-car bracing.

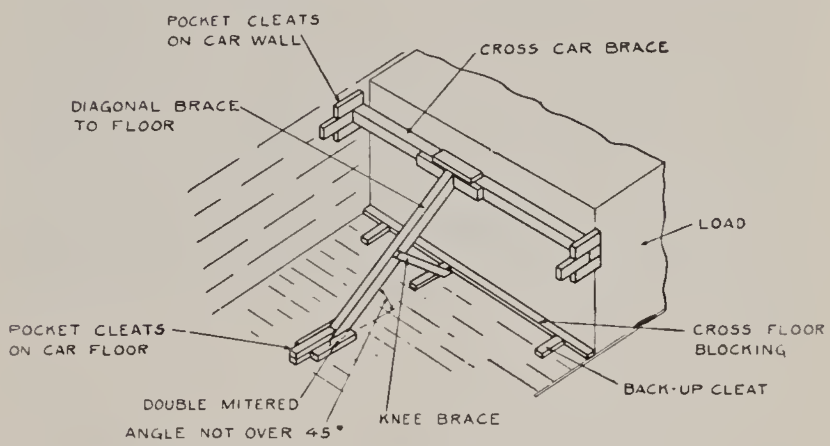


FIGURE 14–79.—Knee brace for cross-car bracing.

For practical reasons, final leveling is done after the joists and subflooring, or floor panels, are in place. Accurate leveling is critically important to subsequent construction. After necessary leveling, the substructure is anchored to the foundation. Various types of anchorage are illustrated in figure 14–26.

14.83. Erection Procedure.—Most prefabricators plan their assembly operations to get the outer shell under roof in a day or less; with some types of houses, this is accomplished in less than half a day. The advantages of speedy shell assembly are obvious; the risk of bad weather

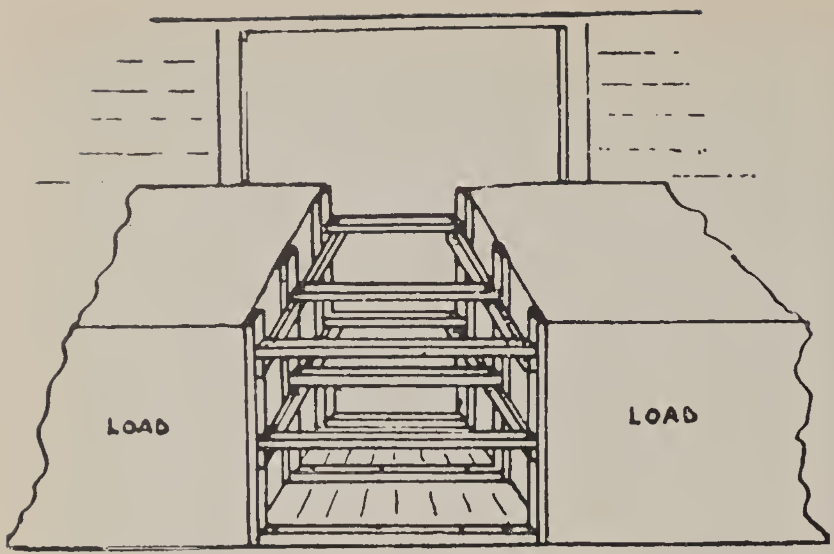


FIGURE 14–80.—Crib bracing in doorway area of car.

and its harmful effects on house parts is greatest while the shell is under construction. Everything that will contribute to speedy shell assembly, including the laying of base plates for wall panels, should be done beforehand to help speed shell erection. All equipment needed to move and lift panels into place and fasten them together should be at the site, ready for use. Careful planning of details, from the loading of the truck at the factory so as to permit unloading of panels in the order needed to an orderly plan of erection of panels in sequence, is strongly advised by experienced builders.

14.830. Sequence of Operations.—The specific order in which panels are erected will depend somewhat upon the type of house. Typical of most systems, however, is that followed by one manufacturer of panelized houses. The truck containing all panels and accompanying plates, corner posts, and other parts is backed to one corner of the building foundation, and erection of corner wall panels begins at the diagonally opposite corner (figs. 14–82 and 14–83). In-

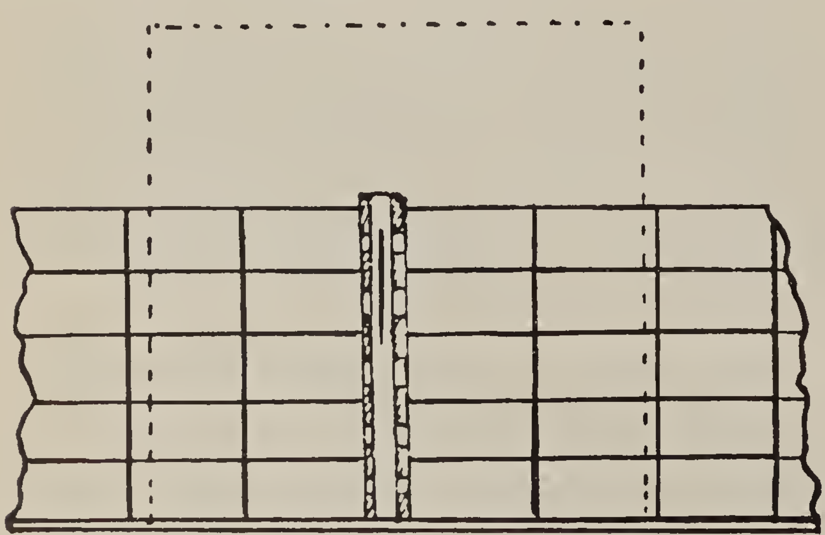


FIGURE 14–81.—Double-faced bulkhead in doorway area.

FIGURE 14–82.—Placing corner panels of exterior wall.

terior partition panels are set up as erection of the outer walls reaches the point at which these panels are connected to them (fig. 14–84). When all wall and partition panels are in place except those at the corner where the truck stands, ceiling panels (fig. 14–85) are next unloaded and attached to the walls and partitions. Again, when the laying of ceiling panels has reached the corner of the building where the truck stands, roof panels are unloaded and laid on top of the ceiling panels in the order in which they will be erected. The gable end on the far side of the building may then be lifted in place, and the process of assembling roof panels begins (fig. 14–86), once more moving toward the end of the building where the truck stands. The final wall panels in the unenclosed corner

FIGURE 14–83.—Nailing corner panels together.

of the building are not erected until all ceiling and roof panels have at least been laid in place; meantime, flooring, trim, and other finishing materials have been moved into the house and piled where they will be conveniently available and out of the way of other erection steps as much as possible.

This sequence of erection steps is, of course, varied to fit particular requirements of building design. For example, it may be that the gable ends are so prefabricated that their installation logically follows that of the roof panels (fig. 14–87) ; or it may be feasible with certain types of panel joints (fig. 14–25) to omit erection of interior cross partitions until the outer shell has been completed. The above sequence of erection steps is applicable primarily for a completely panelized house.

An entirely different plan of erection operations may be followed in large-scale developments, particularly if some combination of prefabricated sections and conventional construction is adopted. The purpose of such combinations may be to achieve greater variety of house design. For instance, the builder may use conventional construction for roofs in order to change the appearance of houses located near one another (fig. 14–88). Under such circumstances, the erection of prefabricated walls and ceilings for each house is carried out much as described above. In order to keep an orderly sequence of roofing, siding, and other operations, crews of men are assigned special tasks so that several operations are under way simultaneously.

FIGURE 14–84.—Lifting a main bearing partition in place.

FIGURE 14–85.—Moving a ceiling panel into position.

FIGURE 14-86.—Erecting roof panels.

FIGURE 14-87.—Installing gable ends after roof panels are in place. Dirt and handling stains on primer-coated wood are cleaned before final coat of paint is applied.

FIGURE 14–88.—Simultaneous roofing operations on different houses. Separate crews erect ridgepoles, rafters, and plywood covering after prefabricated walls, partitions, and ceilings are in place.

With some types of panelized construction, builders find it convenient to position wall and partition panels temporarily with bracing (fig. 14–89) until the entire shell can be permanently tied together. This method permits adjusting wall and ceiling panels more readily for exact fit at joints with roof sections, trusses, or rafters. Bracing may also be necessary to hold the first panels in place when shell erection begins, at least until enough wall and ceiling panels are up to afford the necessary rigidity without bracing.

14.831. Site Gluing.—The gluing of wood joints at the building site is affected by factors, such as weather and temperature, that may differ considerably from comparable conditions at the factory, where they are susceptible to much closer control. Field operations, therefore, are much more limited as to kinds of glues available for use, methods of glue and pressure application, and assembly and curing conditions, so that only the casein and resorcinol glues are commonly employed at the site.

The most important glue joints usually made at the building site are those between panels of stressed-cover construction. In most cases, gluing is limited to joints between wall panels, although some types of construction may call for gluing of joints in the floor and in the ceiling panels.

The technique generally employed in gluing panel joints at the building site is that of nail gluing. With this technique, the requirements as to nail size, spacing, and other details are the same as those applicable to nail gluing at the factory (sec. 14.45101). Application is generally by brushing. Information on suitable glues for site gluing is given in section 15.2, in which the essential factors applying to field gluing for repair work are taken up.

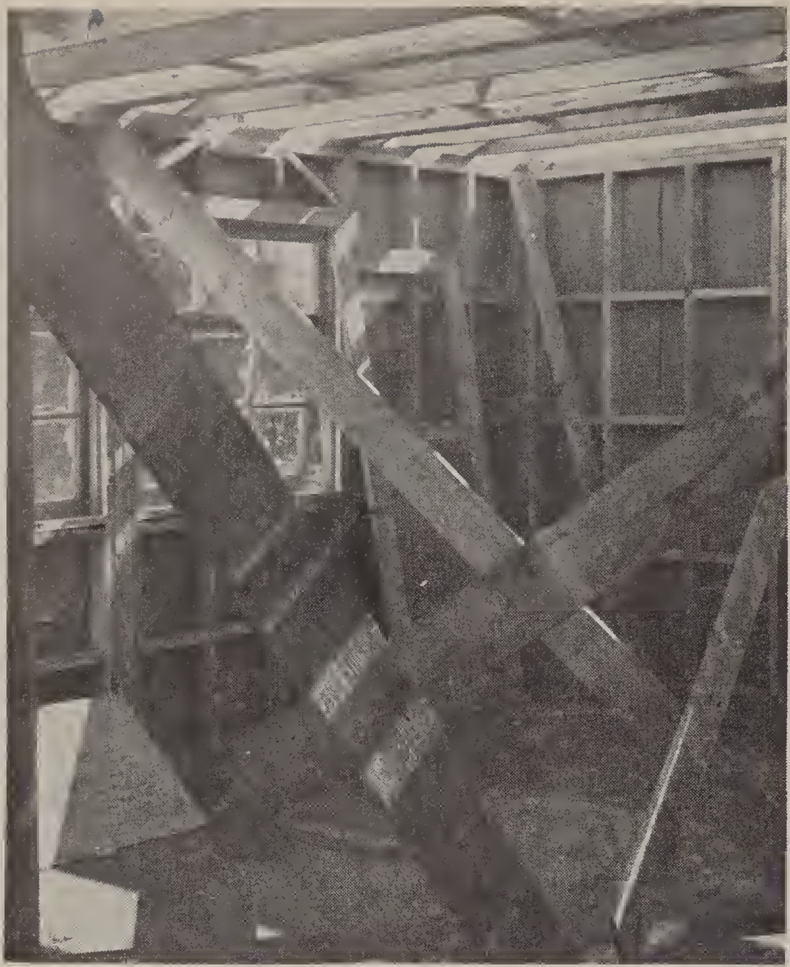


FIGURE 14–89.—Bracing for wall panels. Note bracing blocks nailed to subfloor.

14.832. Assembling of Panels.—The ease with which panels are joined together at the building site, assuming that joints are properly designed, will depend principally upon the care exercised in handling and shipping. Panel joints of the tongue-and-groove type are especially susceptible to damage by rough handling and exposure to moisture for prolonged periods of time. On the other hand, if they are well designed, with beveled edges and proper tolerances, and protected with skid strips against damage in handling, assembly is simple.

Various devices have been developed by prefabricators to facilitate handling of large panels at the building site. Figure 14–90 shows an interior partition being moved into position on a dolly. A somewhat similar contrivance is shown in figure 14–73, and light stepladders useful for setting ceiling and roof panels in place are illustrated in figure 14–10.

Joints between panels are usually calked (fig. 14–91) either before or after assembly. Tongue-and-groove joints generally are calked just before they are set in place and joined, particularly if designed for calking in spline bevels or stud grooves. Calking compound is also

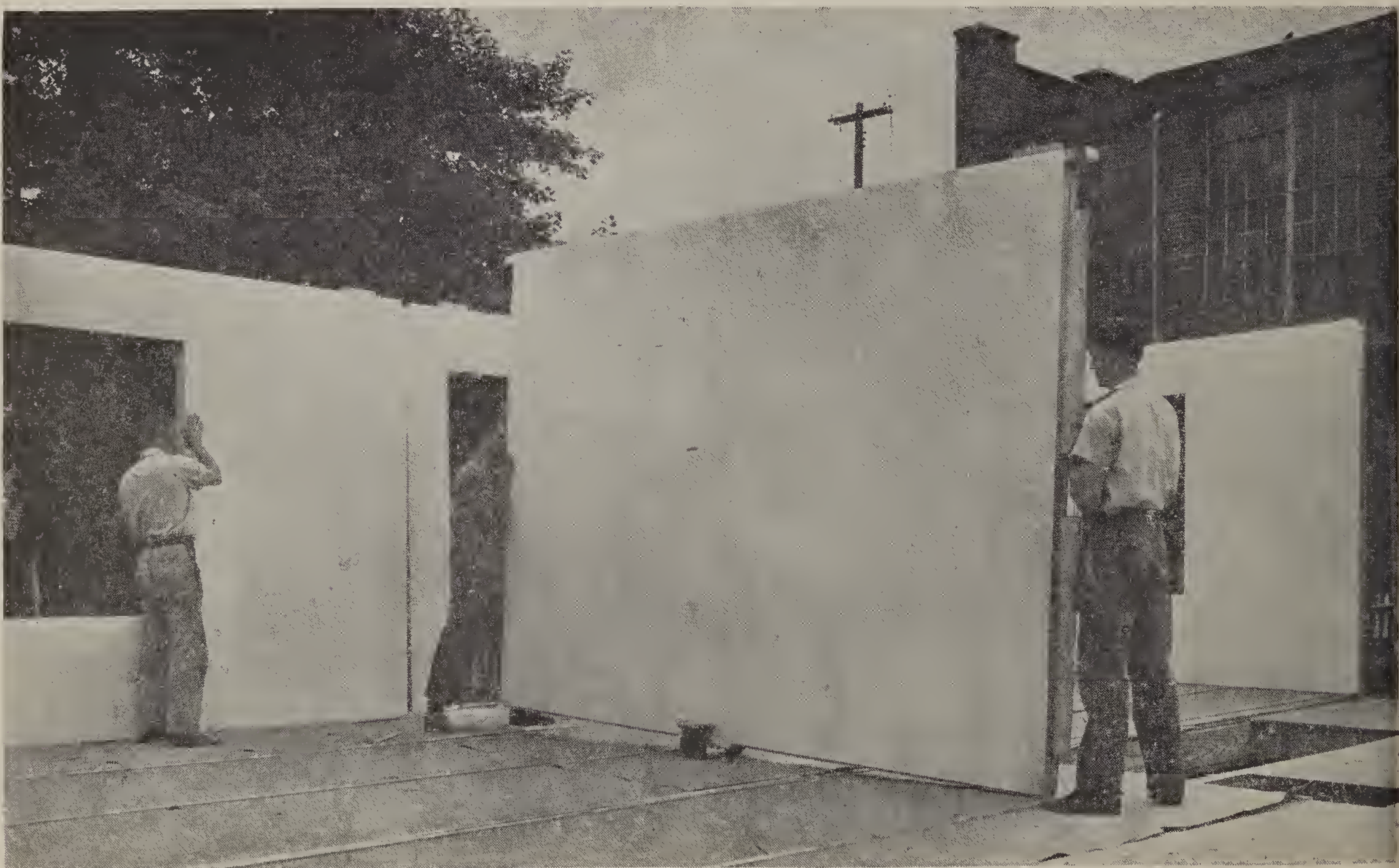


FIGURE 14–90.—Moving interior partition into position with small dolly.

FIGURE 14–91.—Applying composition calking to a stressed-cover panel joint just before setting panel in place.

applied in shallow grooves of panel covers at the joints after the panels are in place if the joint is to be concealed with masking tape or cover strips.

In setting panels in position, it may be necessary to drive them together with a wooden mallet or sledge. The joints should, however, be so designed that this is not necessary. Care should be exercised before using such force to see that the joints are properly alined so that the parts will slip into position without splintering projecting edges of plywood or other covering materials that project beyond the framing of adjoining panels. Light mallet blows should be applied only to the ends of top or bottom plates when moving panels laterally into position. Accurately assembled panels should give no trouble in vertical alinement of joints; occasionally, however, it may be necessary to plane an edge of one panel cover to line it up with the adjoining cover for a tight fit. Where battens are placed over joints, greater variations in tolerance fit of adjoining covers are permissible, as the battens will conceal them.

Panels that are bolted together, as illustrated in figure 14–23, *A* and *B*, generally require accurate lateral alinement in order to match up bolt holes; elongated receiving holes usually

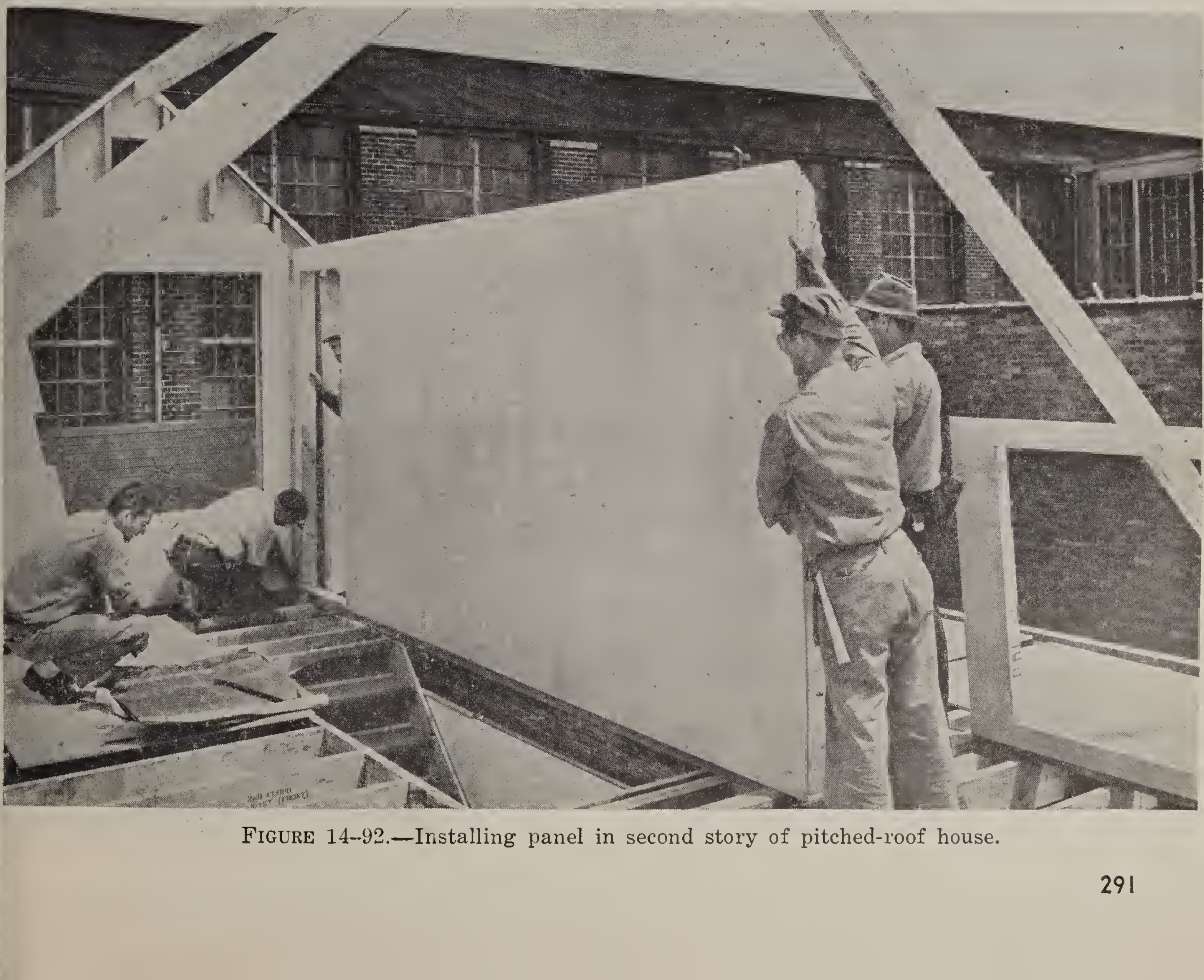


FIGURE 14–92.—Installing panel in second story of pitched-roof house.

FIGURE 14–93.—Cutting plywood to conform to hip of roof.

compensate for any slight variations in vertical alinement (sec. 14.6).

14.833. Roof Assembly.—Most of the prefabricated houses mass produced for the small-house market are of pitched-roof design. As a rule, roof framing is conventional in type, although panelized covering may be used. Occasionally, a pitched roof may enclose second-floor bedrooms. Figure 14–13 shows a type of truss construction designed for this purpose.

Figure 14–92 also shows an adaptation of conventional joist-and-rafter construction designed to utilize second-story space as bedrooms. Prefabricated panels may enclose the space as shown in figure 14–93, or the ceiling can be framed with collar beams tying the rafters together at a height ample for headroom. Plywood may be used for the subfloor, nailed directly to the joists. The use of collar beams and plywood subfloors contributes substantially to the rigidity of the roof structure.

Only the inhabited portion of the second-story space is insulated (fig. 14–18). The blanket-type insulation is laid between roof rafters and brought down between the studs of the partition wall panels of second-floor rooms rather than being extended to the eaves.

The use of plywood for roof coverage is growing, particularly with conventional roofs of the more intricate designs, such as hip, gambrel, mansard, and their variations. With power tools, plywood can be conveniently cut to necessary shape at hips and valleys (fig. 14–93). Plywood provides a suitable base for various roofing materials. Plywood at least one-half inch thick is recommended for roofing materials that are held in place by nails, such as wood and asphalt shingles or slate.

14.834. Trim and Finish.—Cover boards, baseboards, corner moldings, and similar trim all afford convenient methods of concealing variations of tolerance at critical points, such as the

corners, eaves, and foundation lines of buildings (sec. 14.6) and interiors of rooms. All exterior trim at the eaves, including gutters, cornices, and moldings, should be applied before any type of roofing is laid.

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REPAIR TECHNIQUES

15.0. GENERAL. — Repairs to prefabricated house parts are necessitated by (1) damage in the plant, during shipment, or at the building site; and (2) rejection of parts for any reason by plant inspectors (sec. 14.6). In both cases, repair constitutes a salvage operation and is important in proportion to the volume of production in the individual plant. Moreover, while the prefabricator is not primarily concerned with maintenance and repair of finished houses, customers may at times inquire as to recommended methods of repairing damage to stressed covers and other parts. Some prefabricators maintain service departments for such work.

The skill, technique, and care necessary for the successful repair of damaged or otherwise defective parts depend in great measure upon the type of construction to be repaired. Construction consisting of sheathing boards nailed to studs or other framing can usually be repaired rather simply by installing new members. Stressed-cover construction, on the other hand, requires considerable care and good technique if it is to be repaired without materially lowering the strength of the construction or marring the finished appearance. This section is primarily devoted to techniques necessary for the proper repair of panels with a stressed covering on both sides. Some of the techniques described, however, can be easily adapted to repair of other glued constructions as well, such as unbalanced ceiling or roof panels consisting of a framework covered with plywood on only one side.

The repair methods shown are particularly adapted to conditions at the site. Repairs in the factory can utilize the same methods, usually under more convenient circumstances than prevail at the building site during or after construction.

Normally, repairs are accomplished by trimming away the damaged portion of the plywood or framing members and inserting a new piece. In all cases, two conditions must be met by these repairs: (1) The cross-sectional area of the joint must be at least equal to that of the damaged part; and (2) the grain direction of the repair part should always match that of the original, whether plywood or solid wood.

Most of these repairs involve gluing and frequently, the parts to be repaired have a natural finish. Where natural finishes are involved, the proper glue must be selected to prevent discolorations at the glue line.

When the moisture barrier is damaged, or when the barrier must be partially removed to facilitate repairs, it must also be repaired to restore its original effectiveness.

The final step in all repairs is to restore the finish to its original condition by blending the refinished repaired section into the surrounding finish or by refinishing the whole section.

15.1. REPAIR TYPES.—Generally, repairs fall into one of two classes: (1) emergency (temporary) repairs, and (2) permanent repairs. Emergency repairs are made only as a temporary measure, generally at the building site after construction is well along or completed, and should be replaced at the earliest opportunity. Permanent repairs should be made as soon as possible. Prime considerations in making them are quality, strength, and permanence.

15.2. REPAIR GLUING.

15.20. Repair Glues.—The glue to be used in the repair of prefabricated housing panels of stressed plywood construction should be of the room-temperature-setting type. Any of the glues recommended for fabrication in section 11.1 may be used provided the conditions of their use are fulfilled. Repairs at the site must sometimes be made under adverse temperature conditions, thus limiting the selection of glue to those that will cure under such conditions. The effect of temperature on the conditions under which recommended glues may be used is discussed in section 11.2. For repairs at the factory, a wider selection of glues is available.

Because of temperature limitations and requirements, availability, and other factors af-

fecting the choice of glue, only the resorcinol and casein glues are recommended for repair at the building site.

15.21. Working Life of Repair Glues.—When glue has reached the end of its working life it has become so thick that it can no longer be satisfactorily spread (sec. 11.33). The working life of mixed glues is greatly affected by temperature. This temperature effect is shown in table 15–1. Some resorcinol glues may have somewhat longer or shorter working lives than are listed in table 15–1.

TABLE 15–1.—*Approximate typical working life of resorcinol and casein glues at several temperatures*

Temperature	Resorcinol glue	Casein glue
° F.	*Hours*	*Hours*
40	60	60
50	30	28
60	14½	15
70	7	9
80	3½	5½
90	1½	4
110	½	2¾

15.22. Assembly Time for Repair Glues.—Pressure should be applied to the joint before the glue becomes too thick to flow (sec. 11.35). Where the surfaces are coated with glue and exposed freely to the air (open assembly) a more rapid thickening of the glue occurs than when the pieces are laid together as soon as the glue is spread (closed assembly).

Some resorcinol glues are rather thin immediately after mixing, and a short open or closed assembly period is desirable before pressure is applied to the joint. Recommended open and closed assembly periods for resorcinol and casein glues are given in table 15–2.

TABLE 15–2.—*Assembly periods for glues used in repair at 70° to 80° F.*

Period	Resorcinol glue		Casein glue	
	Open	Closed	Open	Closed
	Minutes	*Minutes*	*Minutes*	*Minutes*
Minimum	5	10	0	0
Maximum	12	60	10	20

Since most repair gluing operations involve both open and closed assembly periods, the permissible limits for any operation can be computed readily from the approximation that 1 minute of open assembly results in about as much thickening of the glue as does 2 minutes of closed assembly. For example, with casein glue in an operation requiring 5 minutes of open assembly, which is equivalent to about 10 minutes of closed assembly, an additional 10 minutes of closed assembly would be permitted.

If the wood is very dry or the wood and air temperatures are above 80° F., as during hot summer days, more rapid thickening of the glue would occur and the allowable assembly periods will be less than those shown in table 15–2.

15.23. Duration of Pressure for Repair Gluing.—Joints should be left under pressure at least until they have developed sufficient strength to withstand internal stresses tending to separate the members, as well as strength to withstand such stresses as may be placed on the joints during the removal of the screws or subsequent repair work. Table 15–3 gives the minimum time in hours that joints should be left undisturbed under pressure at various temperatures.

TABLE 15–3.—*Minimum time under pressure for joints at various temperatures*

Temperature of air and material	Minimum time under pressure	
	Resorcinol glue	Casein glue
° F.	*Hours*	*Hours*
20–29	Not to be used	48
30–39	Not to be used	24
40–49	144	16
50–59	120	12
60–69	24	8
70–79	8	6
80–89	4	5
Above 90	2	4

15.3. EMERGENCY REPAIRS.

15.30. Stressed-cover Repairs.—The main purpose of the emergency or temporary repair to stressed covers is to keep rain, snow, and cold from entering the walls or the interior of the house. Ordinarily, holes resulting from puncture have no appreciable effect on strength (sec. 14.11111). Such repairs are made only at the building site. Temporary repairs must often be made quickly with materials available. Two simple, effective methods are the patch of waterproof paper and pressure-sensitive tape and the plywood-putty patch.

15.300. Patch of Waterproof Paper and Pressure-sensitive Tape.—A 50–50–50 laminated water-

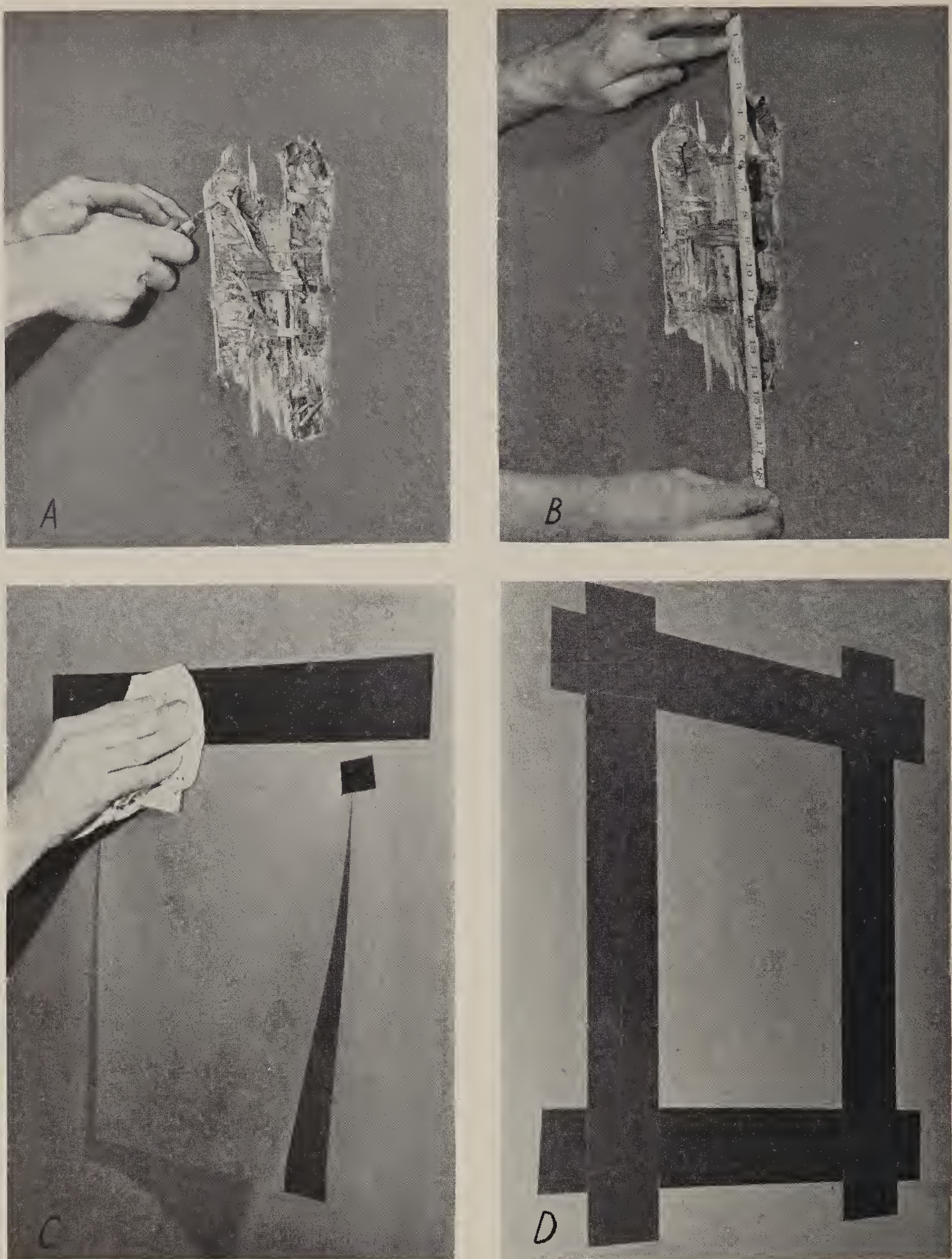

FIGURE 15-1.—Steps in making a patch of waterproof paper held in place with pressure-sensitive tape. *A*, cutting away splinters; *B*, measuring damaged area for size of patch; *C*, applying tape; *D*, completed patch.

proof paper or an asphalt felt of 15-pound grade or heavier can be used to make a temporary patch. Thin sheet metal, tinplate, flashing metal, or any other thin waterproof material may be substituted for the waterproof paper. The use of laminated paper with reinforcing strands imbedded in the laminant is not recommended. The pressure-sensitive tape (a tape that will adhere merely by applying light rubbing pressure by hand) should have a treated cloth back and be not less than 3 inches in width.

Steps in making a patch of waterproof paper and pressure-sensitive tape are (fig. 15–1):

1. Examine the edges of the break, cutting away with a knife all splinters that might puncture the waterproof paper. Measure the longest dimensions of the break in both directions.

2. Remove all powdered paint and dirt from the panel along the tape line with fine sandpaper. Remove dust with a clean cloth or brush. (This step can be omitted if the paint is clean, not checked, or not in the powdered stage.)

3. Cut the paper 6 inches larger than the dimensions of the damage to allow for a 3-inch overlap on all edges. Mark the paper 1½ inches in from all edges for a tape guide.

4. Mark the patch location on the panel, so that the patch will be centered over the damaged area. Fasten the patch to the panel temporarily with two small pieces of tape, one on each side approximately 2 inches down from the top edge.

5. Determine the length of the tape—length of patch plus 6 inches, to allow a 3-inch overrun on the panel at each edge of the patch.

6. Apply top, bottom, and side tapes in this order, following guide lines on paper. Guide lines will insure equal division of tape on the patch and panel. Rub each tape vigorously with a clean cloth. Special care must be taken along edges and at laps to insure adequate adhesion.

15.301. Plywood-putty Patch.—Sound-One-Side commercial exterior-grade plywood is preferable. Other materials, such as pressed board or sheathing-grade wallboard, can be substituted if necessary for the plywood or if these materials constitute the cover to be repaired. Any good grade of putty can be used. This patch is recommended when the temperature is below freezing. A complete patch is shown in figure 15–2.

FIGURE 15–2.—Completed temporary plywood-putty patch.

The steps in making a plywood-putty patch are:

1. Cut away all splinters that might prevent the patch from lying flat. Measure the longest dimensions of the break in two directions.

2. Cut plywood 6 inches larger than damage dimensions to allow for a 3-inch overlap on all edges.

3. Mark patch location on panel so patch will be centered over damage. Fasten plywood (sound face out) to panel with wire nails spaced 3 inches apart along all edges.

4. Apply a triangular bead of putty along edge of patch with a putty knife.

FIGURE 15–3.—Tools required to make a wood inlay patch.

15.31. Emergency Frame Repairs.—Emergency or temporary site repairs should not be made to the frame unless collapse of a section or entire structure is likely. Splice plates having at least the same cross-sectional area as the original can be used where a portion of the original member remains intact. Where the original member has been completely destroyed, supporting members can be nailed to the panel faces.

15.4. PERMANENT REPAIRS TO STRESSED COVERS.

15.40. General.—Damage occurs more frequently to the cover than to any other part of the structure, during factory production as well as in shipment or at the erection site. Damage may vary from small holes the size of a pencil to large holes extending over several square feet.

Whenever it is necessary to remove portions of damaged plywood from the framework, care must be taken not to damage the surface of the frame. Plywood of the softer-textured species, such as yellow-poplar or white pine, can often be removed by carefully prying the edges loose with a chisel and then carefully tearing the plywood off. This normally leaves part of the inner face ply on the frame and this can be removed by planing, scraping, or sanding. Plywood of the harder species should first be cut or sawed on both sides of the framing member, leaving a strip just the width of the framing member. Most of this strip of plywood can then be removed with a chisel and the remainder by planing, scraping, or sanding.

Repairs to panels with natural finish are the most difficult to make. Not only must the grain direction and color of the original be matched, but care must be taken in choosing the glue to prevent discoloration at the glue line.

15.41. Repairs to Damage Not Puncturing Cover.

15.410. Use of Paste Wood Fillers.—Scratches and dents not puncturing the plywood cover may often be repaired without removing a por-

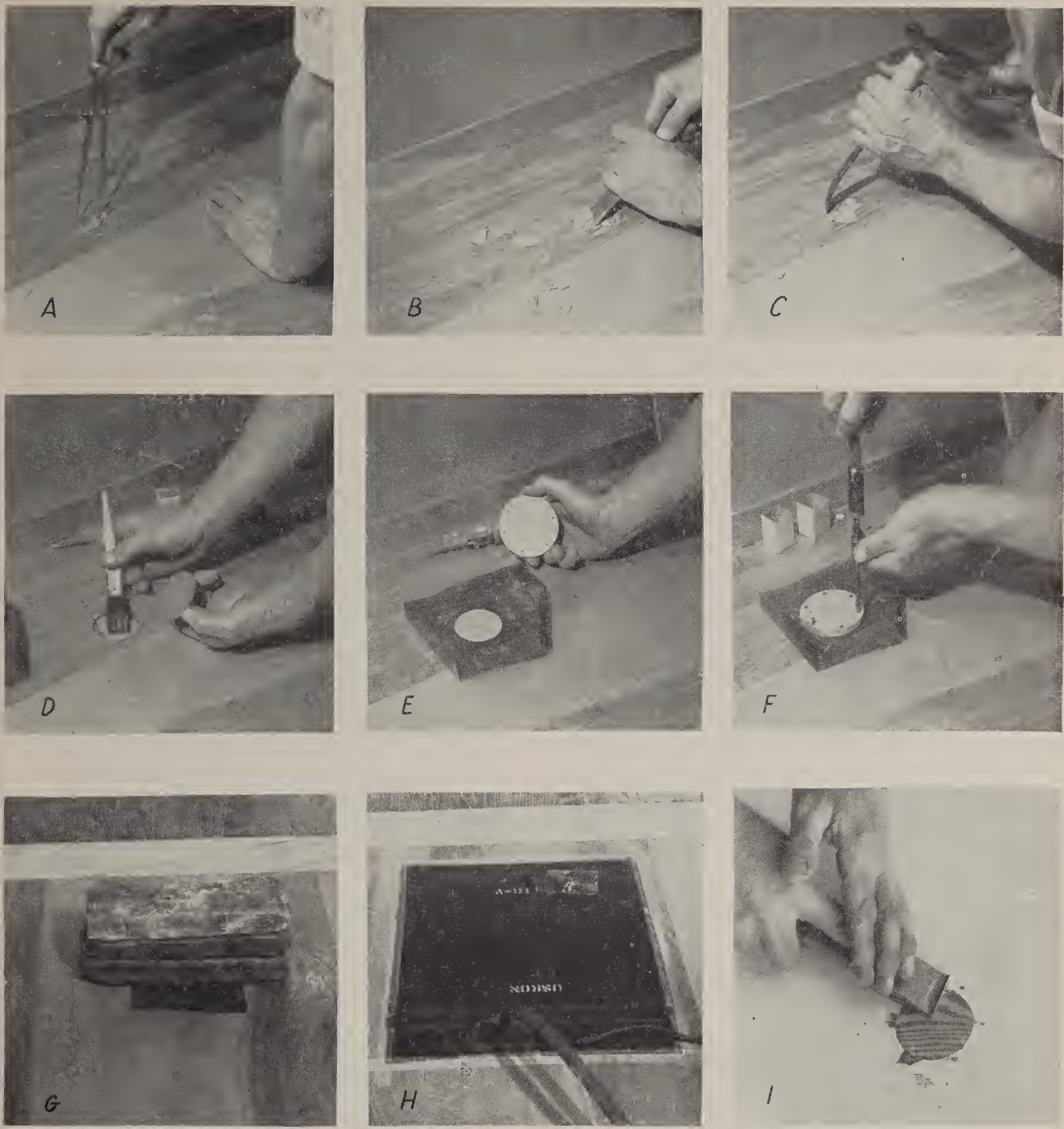

FIGURE 15–4.—Steps in making a wood inlay patch. *A*, outlining enlarged patch with dividers; *B*, removing wood with chisel; *C*, cutting edges with gouge; *D*, applying glue with brush; *E*, inlay, cellophane, and chipboard in place; *F*. applying screw pressure; *G*, applying pressure with lead weights; *H*, applying pressure and heat with electrically heated vacuum blanket; *I*, scraping off glue squeeze-out after glue has set.

tion of the plywood. Commercial paste wood fillers can be used. The damage should be dry and clean, but not necessarily smooth; rough surface insures better adhesion. If the damage is exceptionally deep, the hole should be filled with the paste in layers, allowing each layer to dry before another is applied. Fill the damaged area slightly higher than the surrounding surface. After the final layer has dried, the filler can be sanded flush with the original surface.

15.411. Repairs with Wood Inlays.—Damage not puncturing the cover may be repaired by using

a round or square inlay. Inlays should be one-half the thickness of the skin; they should not exceed 4 inches in diameter or 4 by 4 inches square. This type of patch is recommended for floors and wall panels of natural finish. It can be made with simple hand tools (fig. 15–3).

Steps in making a wood inlay are (fig. 15–4):

1. Lay out the size of patch. Center dividers and draw a circle.

2. Remove the wood to proper depth with a chisel, hand router, or portable power router. If a chisel or a hand router is used, the wood on the edge of the hole must first be removed with a gouge or plug cutter.

3. Make a patch to fit the prepared hole, and glue the patch into place with the face-grain direction matching that of the original surface. Use cellophane or wax paper over the patch to prevent extruded glue from binding the pressure plate to the patch. A piece of chipboard paper at least one-sixteenth inch thick should be placed between the cellophane and the plate if pressure is to be applied by screws. The paper should be the same size as the patch.

4. Apply pressure. The pressure plate should be made of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch plywood, and should be 2 inches larger than the patch if pressure is to be applied with screws; a single row of wood screws, $\frac{1}{2}$ inch from the edge of patch and spaced $1\frac{1}{2}$ inches apart should be used. The pressure plate should be the same size as the patch when weights or a vacuum blanket are used. To reduce setting time, a heated vacuum blanket can be used, but precaution should be taken to avoid excessive heat, which may ruin the surrounding finish.

5. Fill, sand, and refinish the patch.

15.42. Repairs to Punctured Cover.

15.420. Repair with Round Plug Patch.—The round plug patch may be used on plywood covers that have been punctured, provided that the damage does not involve the supporting structure under the cover. The dimensions of a convenient size of round plug are shown in figure 15–5. The patches must be prepared with the face grain carefully oriented. Pressure should be applied with No. 5 wood screws spaced $1\frac{1}{2}$ inches apart; screws should be approximately as long as the total thickness of patch and doubler. The screws can be left in permanently or removed after the glue has had sufficient time to set. If left in permanently, flat-head brass screws are recommended, otherwise round-head screws will suffice. Permanent screws should be sunk below the surface of the panel or patch. The thickness of the doubler should equal or exceed that of the patch.

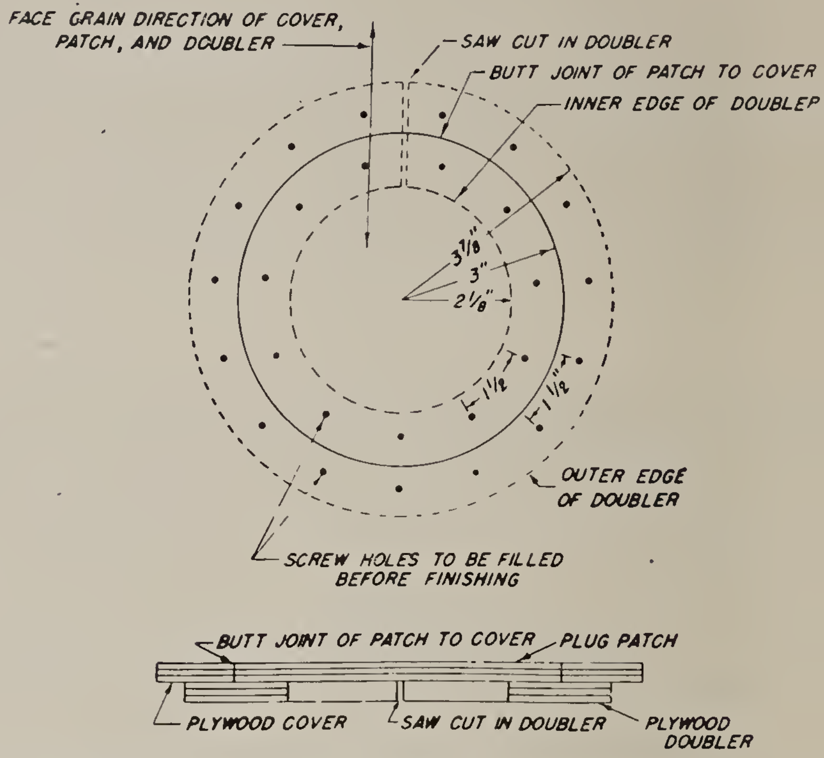

FIGURE 15–5.—Dimensions of a convenient size of round plug patch.

Steps in making a round plug patch are (fig. 15–6):

1. Explore the area about the hole to be sure it lies at least the width of the round doubler from a plate or a stud.

2. Lay a previously prepared round plug patch over the damage and trace around the patch. Saw to the line and trim the hole edges with a rasp and sandpaper.

3. Remove insulation.

4. Drill screw holes in the panel. Drill matching holes in the patch and doubler.

5. Mark the exact size of the patch on one surface of the round doubler and apply glue to the area of the doubler outside the patch line. Insert the doubler through the hole and bring it, glue side up, to the under side of the cover, with the pencil outline of the patch matching the edges of the hole.

6. Screw the doubler to the panel.

7. Repair the vapor barrier if it is damaged (sec. 15.6) and replace the insulation.

8. Apply glue to the remaining surface of the doubler and the corresponding surface of the patch.

9. Lay the patch in position over the doubler.

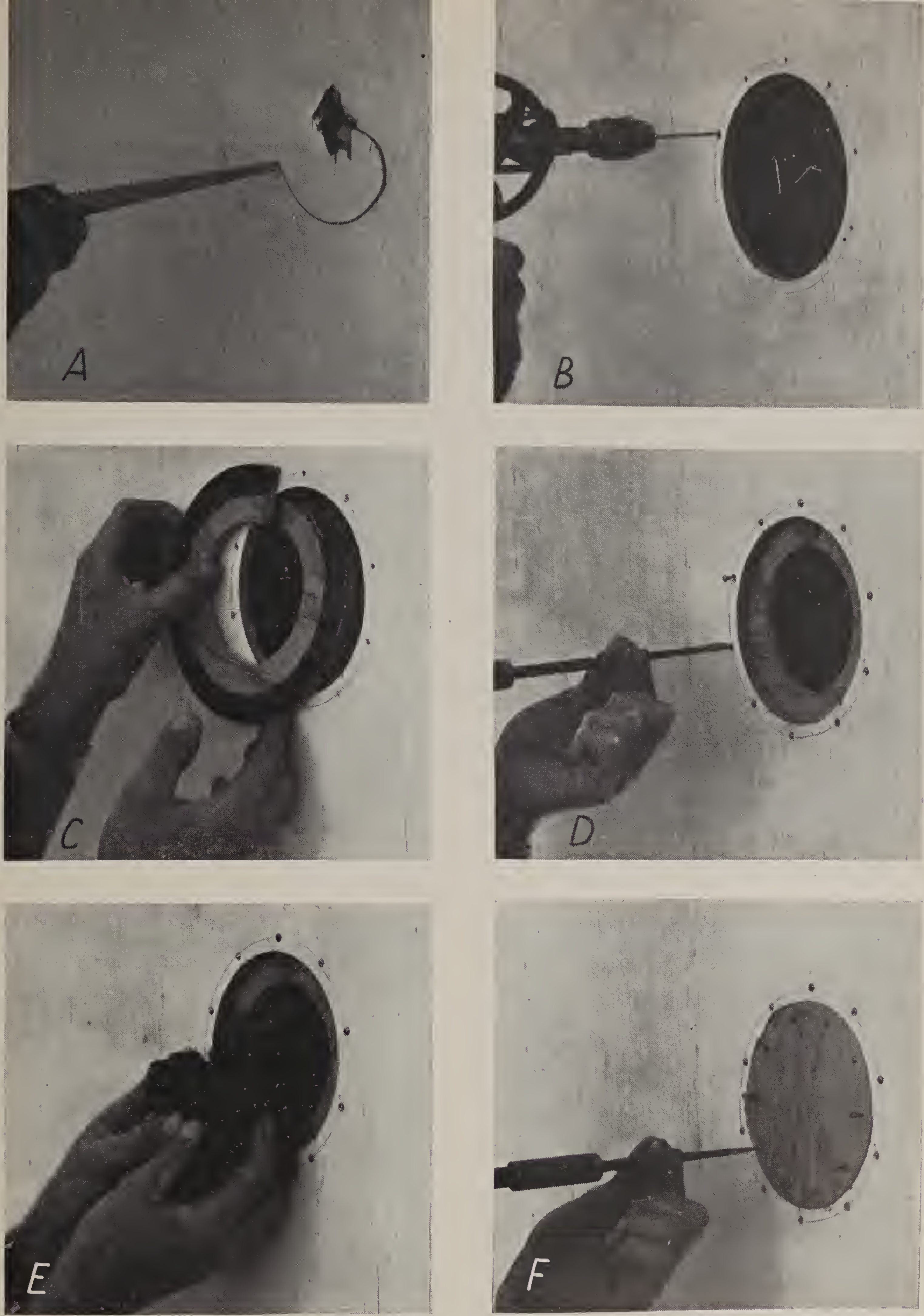

FIGURE 15–6.—Steps in making a round plug patch. *A*, sawing hole around damage; *B*, drilling screw holes for attachment of doubler; *C*, *in*serting doubler; *D*, screwing doubler in place; *E*, replacing insulation; *F*, screwing plug patch to doubler. Glue squeeze-out is scraped off after the glue has set, screw holes filled, and finish applied.

FIGURE 15–7.—Hand tools necessary to make rectangular plug patch.

10. Screw the patch to the doubler.

11. Remove the screws, if not permanent, after glue has set.

12. Fill, sand, and refinish the patch.

The round plug patch can be made more conveniently when a portable router is available. Essentially the steps are the same as for making the patch with hand tools. Use a template to guide the router so that the hole and patch fit accurately. A collar over the router bit rides the template edge and determines the cut. Two interchangeable collars for the router, with the proper relation of their sizes, allow the same bit and template to be used for both hole and patch.

15.421. Repair with Square or Rectangular Plug Patch.—The square or rectangular plug patch can be used for cover repairs that exceed the size limitations of the round plug patch. Its use is not limited to the area between the framing members, it may extend over one or more members or across the entire panel. Plywood doublers $2\frac{1}{2}$ inches in width, having a thickness at least equal to the plywood cover, should be used. The face-grain direction of the doubler and the cover should be the same. Double rows of screws are used to fasten doublers to the panel and the patch to the doublers. A screw spacing of 2 inches in staggered rows is recommended. Permanent screws recommended are No. 5 flat-head brass screws; temporary screws are No. 5 round-head screws. Screw length should be approximately equal to the total thickness of the patch and doubler. Figure 15–7 shows the hand tools needed and figure 15–8 the steps necessary in making a square or rectangular plug patch.

Steps in making a square or rectangular plug patch are:

1. Inspect damage to determine its extent and to see if damage occurs to studs or other frame members. Determine the size of patch to use.

2. Cut the hole large enough to remove all

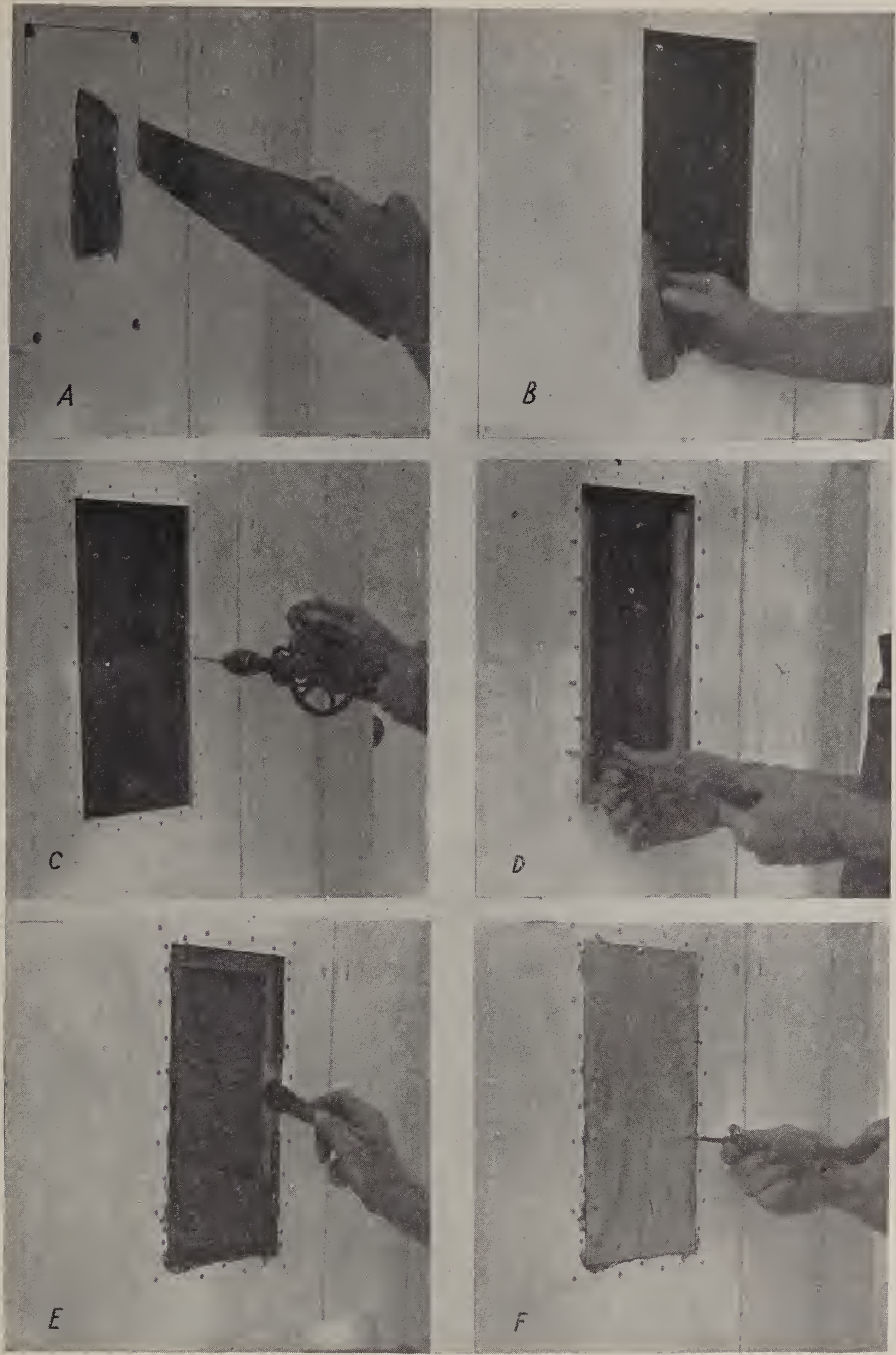

FIGURE 15–8.—Steps in making a rectangular plug patch. *A*, sawing out hole; *B*, trimming edge of hole; *C*, drilling screw holes after removal of insulation; *D*, screwing doubler to cover; *E*, applying glue to doubler; *F*, screwing patch in place. Excess glue should be scraped off after glue has set.

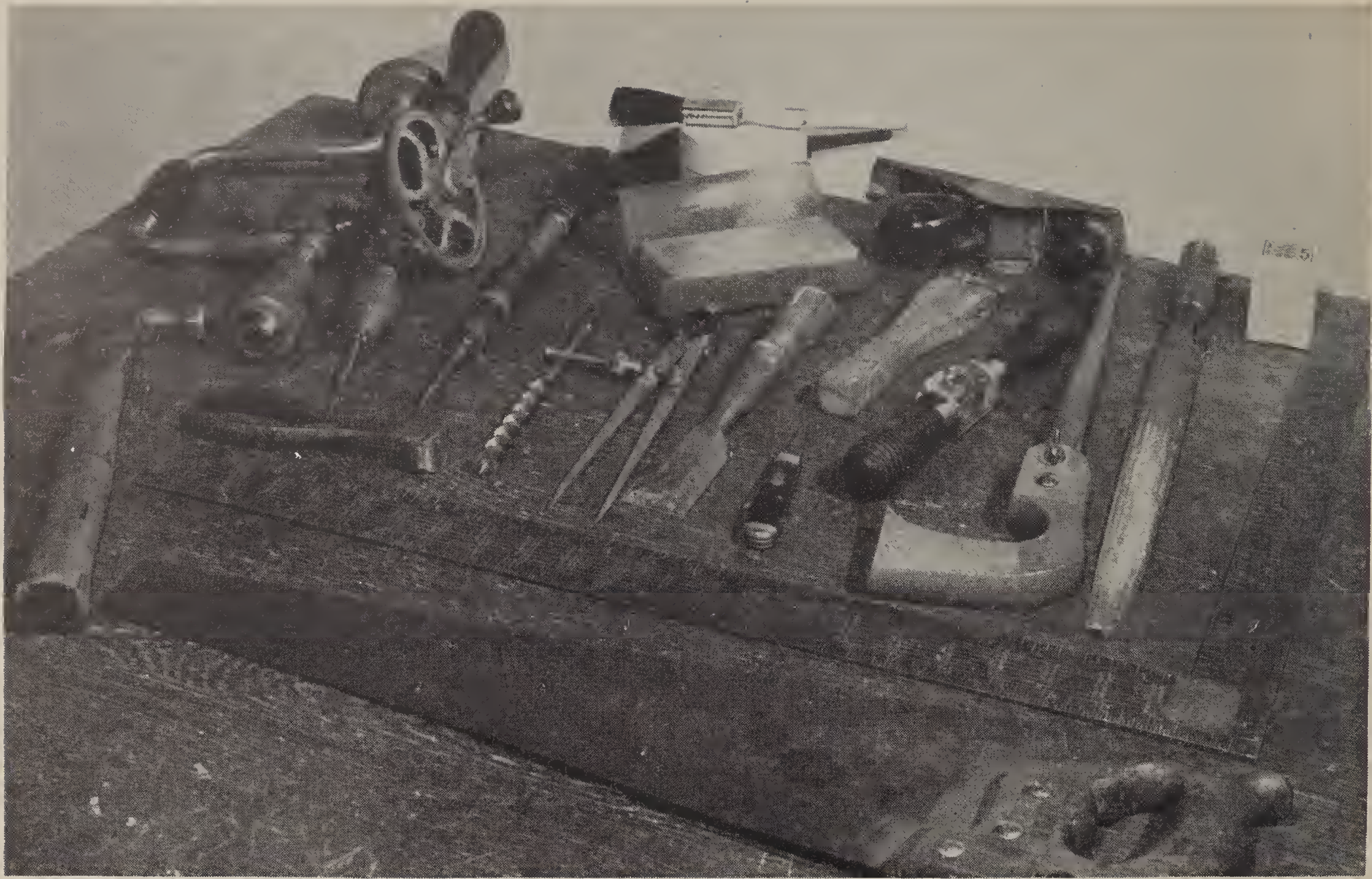

FIGURE 15–9.—Tools needed to make a scarfed patch.

damaged cover. Use hand tools carefully to avoid splintering. Cut and trim accurately.

3. Remove insulation and check the vapor barrier for damage.

4. Drill screw holes in the panel, patch, and doublers. Care should be taken to match the holes in the respective parts.

5. Draw a line down the center of the doublers. Spread glue on one-half of the face of each. Insert the doubler through the hole and bring it, glue side up, to the under side of the cover. The line on the doubler should correspond to the edge of the hole.

6. Screw the doubler to the panel.

7. Repair the vapor barrier if necessary (sec. 15.6) and replace insulation. A blanket type should be used to replace loose insulation if the hole is large.

8. Apply glue to the remaining surface of the doubler and to the corresponding surface of the patch, as well as on exposed studs and corresponding areas of the patch.

9. Lay the patch in position over the doubler. Orient its grain direction to match that of the cover.

10. Screw the patch to the doubler. Nail the patch to the studs with fourpenny finishing nails spaced 3 inches apart.

11. Remove screws, if not permanent, when the glue has set.

12. Scrape, fill, sand, and finish the patch to blend with the surrounding surface of the panel.

15.422. Repair with Scarfed Patch.—The scarfed patch, like the square or rectangular plug patch, can be used for cover repairs that exceed the size limitations of the round plug patch. One in 4 is the steepest scarf slope recommended for this type of patch. Plywood backing strips equal to the width of the scarf cut, and as thick or thicker than the cover, should be used. The face-grain direction of backing strip and cover should be parallel. A double row of screws should be used to apply pressure to the backing strip, but nail strips may be used to apply pressure to the scarf joint. The hand tools needed for on-site repair and necessary steps in making a scarfed patch are shown in figures 15–9 and 15–10.

Steps in making a scarfed patch are:

1. Inspect the damage to determine its extent

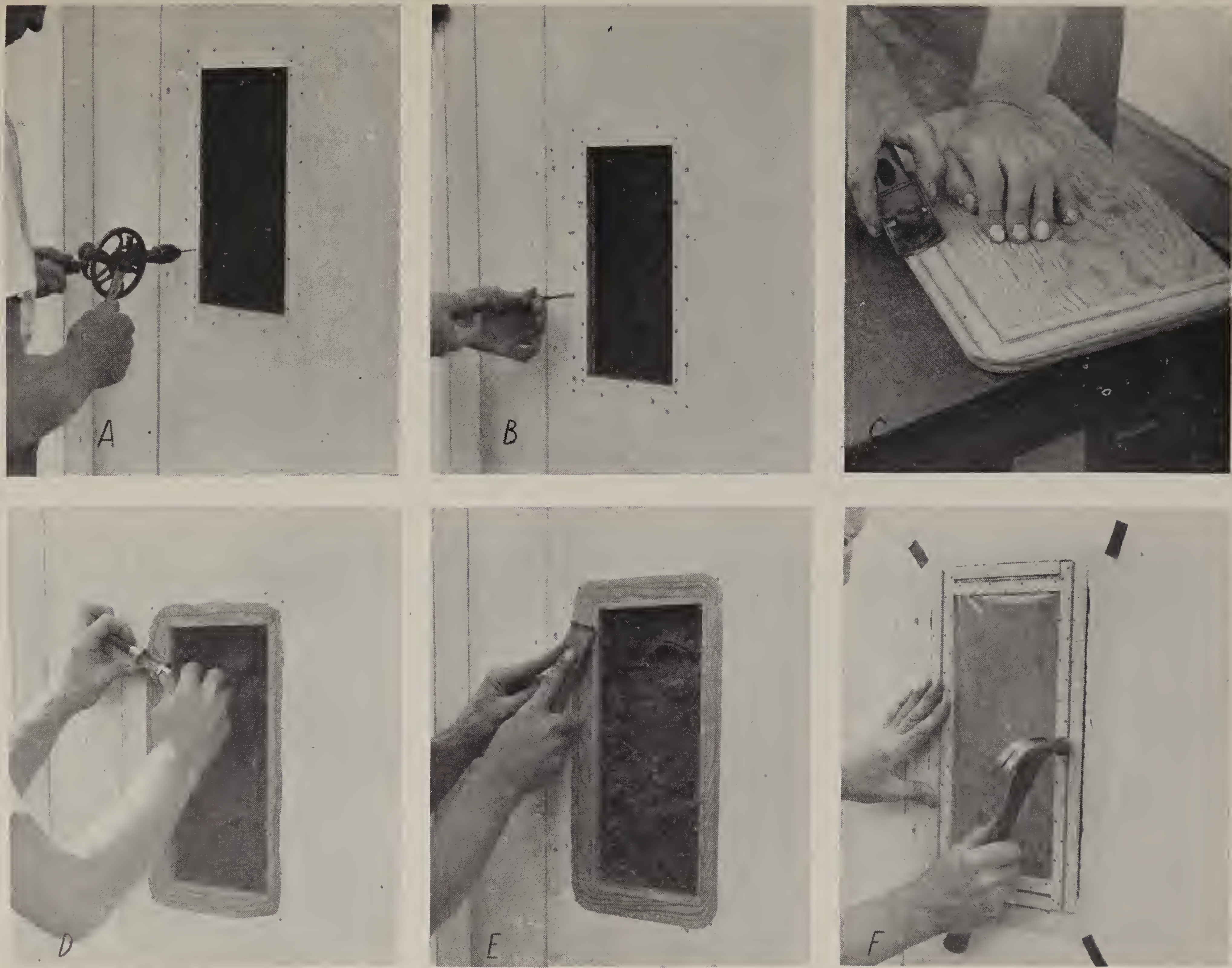

FIGURE 15–10.—Steps in making a scarfed patch. *A*, drilling holes in cover for screws to hold backing strip while glue sets; *B*, screwing backing strips to cover; *C*, scarfing patch; *D*, cutting scarf with spokeshave; *E*, smoothing scarf with scraper; *F*, fastening patch with nailing strips.

and to see if damage occurs to studs or other frame members. Determine the size of patch to use.

2. Cut the hole large enough to remove all damaged cover. Use hand tools carefully to avoid splintering. Cut and trim accurately.

3. Remove the insulation and check the vapor barrier for damage.

4. Drill holes in the panel and backing strip. Care should be taken to match the holes.

5. Spread glue on one face of the backing strip. Insert the backing strip through the hole and bring it, glue side up, to the under side of the cover. The edge of the strip should be flush with the edge of the hole.

6. Screw the backing strip to the cover.

7. Mark the limits of the scarf around the hole and determine the patch size.

8. Scarf the patch with a hand plane, rounding the corners and sanding it smooth.

9. After the glue holding the backing strips has set, remove the screws.

10. Scarf the hole with a spokeshave, small plane, or chisel. Round the corners with a fine rasp. Smooth the scarf with a scraper and sandpaper.

11. Replace the insulation and, if necessary, repair the vapor barrier (sec. 15.6).

12. Glue the patch in place, with the face-grain direction matching that of the original surface.

13. Apply the nailing strips to all sides of the patch and allow the glue to set. Use paper or cellophane under the nailing strips.

14. Remove the nailing strips and scrape away all extruded glue. Prepare the patch for finishing.

15.5. PERMANENT REPAIR TO FRAMEWORK.

15.50. General.—The framework of a stressed-cover plywood prefabricated house includes such items as studs, plates, splines, cornerposts, joists, and other parts that act as a part of the structure. The only frame repair discussed here is that of the studding. Some of the repair techniques developed for the studding will also apply to the repair of other frame members.

15.51. Repair of Studding.—All joints in the stud itself should be glued. Pressure may be applied by permanent splice plates nail glued to the studs. Care must be taken when replacing the moisture barrier to make all patches moistureproof.

15.510. Splice Plate on One Side.—A splice plate nail glued to one side of the stud may be used when the damage is limited to one or two splits parallel to the grain, or when the edge to which the cover is glued has shallow surface damage.

Steps in making a splice-plate to a stud (figure 15–11) are:

1. Cut away all damaged covering.

2. Remove the insulation.

3. Remove the moisture barrier from one side of the stud.

4. Remove all asphalt paint and glue from one side of the stud for a distance of at least 4 inches longer than damaged portion. (This assumes that the moisture barrier was attached to the side of the stud with asphalt paint, which is good practice but not commonly done.)

5. Cut the splice plate 4 inches longer than the damaged portion of the stud. The splice plate should be not less than the thickness of the stud.

6. Spread glue on the stud and on the cover adjacent to the stud, also to one side and one edge of the splice plate.

7. Position and nail the plate to the stud. The splice plate should extend at least 2 inches beyond each end of the damage.

8. Drive fourpenny finishing nails through the opposite face into the plate. Space the nails 3 inches apart.

9. Replace the barrier, repairing it if necessary (sec. 15.6). Use asphalt paint on the patch and staple or tack it to the cover and stud.

10. Replace insulation.

11. Repair the cover as discussed in section 15.4.

15.511. Butt-joint Splice in Studding.—The damaged section can be replaced with a butt-joint splice when the stud is damaged too extensively to permit use of a splice plate. Steps in making a butt-joint splice (fig. 15–12) are:

1. Cut away all damaged covering.

2. Remove insulation.

3. Remove the moisture barrier from both sides of the stud.

4. Cut the stud off square above and below the damaged section with a saw. Remove the damaged section with a chisel except for a thin layer close to the opposite cover, which should be removed with a scraper.

5. Cut two splice plates at least 8 inches long

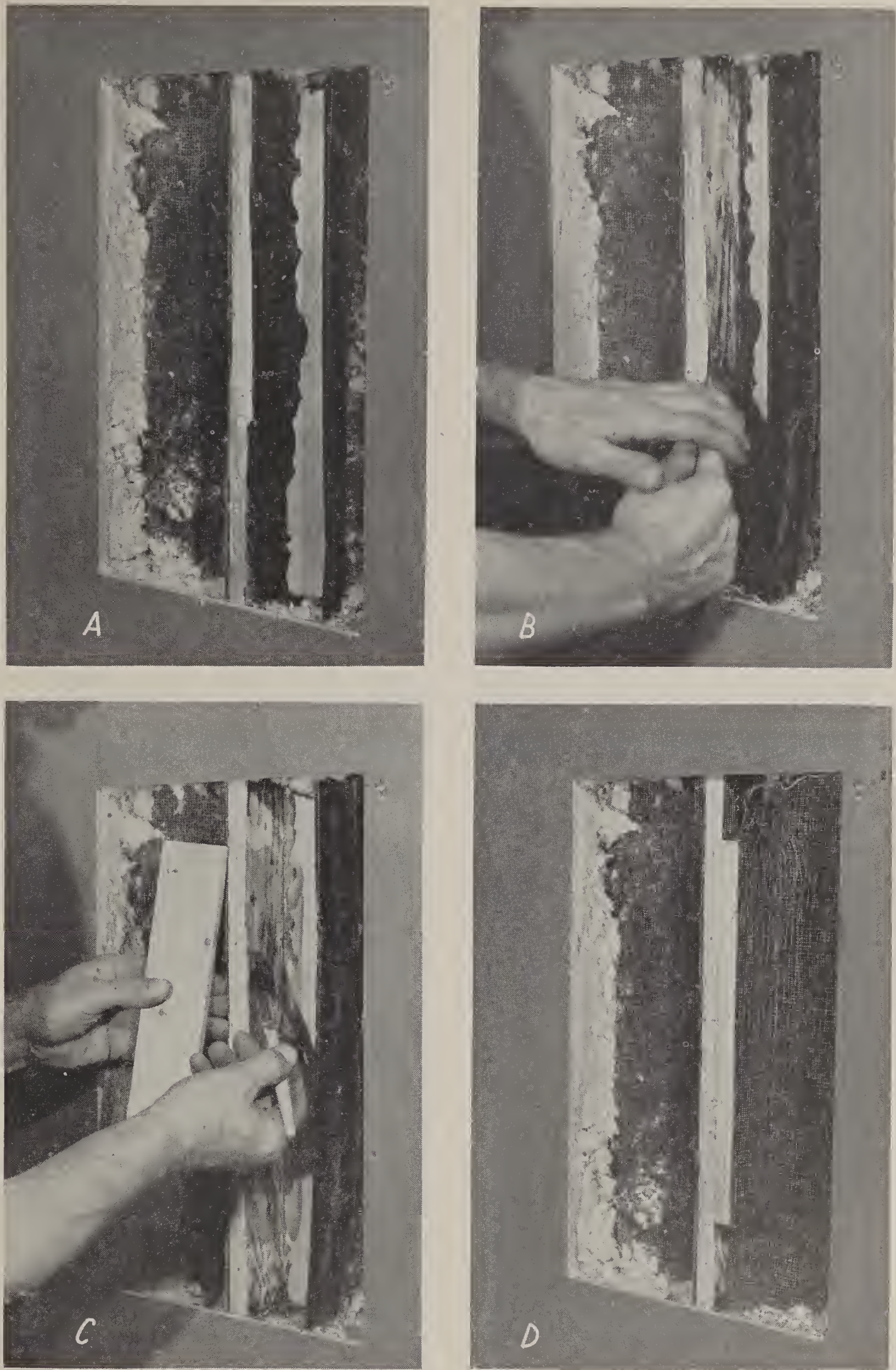

FIGURE 15–11.—Steps in making a splice-plate repair to studding with shallow surface damage on edge. *A*, insulation and moisture barrier removed; *B*, scraping stud clean of paint or glue; *C*, applying glue to stud; *D*, splice plate nail glued in place and covered with moisture barrier patched in place. Dark irregular area in *A* is remains of asphalt paper glued to stud.

FIGURE 15–12.—Steps in making a butt-joint splice repair to badly damaged stud. *A*, cutting out damaged section of stud: *B*, chiseling away damaged section: *C*, applying glue to cover (splice plates have been nail glued to replacement section); *D*. removing glue squeeze-out from butt joints after glue has set.

and of cross-sectional thickness not less than the thickness of the stud.

6. Nail glue the splice plates to the replacement section, allowing a 4-inch overlap at each end.

7. Spread glue on the opposite cover and on one side of the stud 4 inches above and below the cut. Also spread glue on the corresponding edges of the replacement section and plates.

8. Insert the replacement section and nail the splice plates to the original stud.

9. Drive fourpenny finishing nails through the opposite cover into the patch and plates.

10. Replace the barrier, repairing it if necessary (sec. 15.6).

11. Replace insulation.

12. Repair the cover, as discussed in section 15.4.

15.6. Repair of Vapor Barriers.

15.60. General.—The vapor barrier repair method used depends upon the type of barrier installed in the house (sec. 8.23). Barriers commonly installed with fill or blanket insulation are usually less difficult to repair than the curtain types, such as aluminum or solid fiberboard. In all cases, the objective is to get as tight a vapor seal as possible between the original barrier and the repair patch around the edges; asphalt paint is generally used for this purpose.

15.61. Repair of Barriers on Fill or Blanket Insulation.—Vapor barriers used with fill-type insulation are installed separately, being a continuous member across the inner faces of studs or stapled to the sides of studs on a seal of asphalt paint. The nature of the repair depends somewhat upon whether it is made from the interior or exterior side of the wall.

15.610. Barrier Repair When Outside Cover is Removed.—Repair of the barrier when the outside cover is removed is comparatively easy. Smooth out all tears and wrinkles on the original barrier and coat it with asphalt paint at least 3 inches beyond all damage. Coat one side of the patch, which is at least 3 inches larger in all directions than damage, with a material comparable with asphalt paint and tack or staple it over the damage.

15.611. Barrier Repair When Inside Cover Only is Removed.—It is somewhat more complicated to repair the moisture barrier when the inside cover only is removed. For small breaks, such as may occur in conjunction with the making of a small scarf or plug patch, not extending over a stud, two pieces are used, with allowance for a 3-inch overlap on the original barrier at top, bottom, and both sides and a 3-inch overlap in the center. One side of each piece is coated with asphalt paint. A small flat stick approximately 1 inch in width and $\frac{1}{8}$ inch in thickness is inserted between the original barrier and the cover on one side of the hole to hold the original barrier away from the cover. Insert the first piece between the original barrier and the cover, with the coated face toward the insulation. Change the guide stick to the other side and insert the second piece.

For larger damage, extending from stud to stud but not the entire length of the panel the moisture barrier is inserted between the original barrier and the inside cover above and below the hole for a distance of 6 inches or more and held in place by battens, approximately $\frac{3}{16}$ by $\frac{1}{2}$ inch in cross section, tacked or stapled to the studs or backing strips on the sides of the opening as shown in figure 15–13. Effectiveness of the barrier patch can be improved by using asphalt paint on parts inserted above and below the hole and also on flaps placed behind the battens.

For damage extending from stud to stud the entire length of the panel, necessitating removal of the entire cover over one or more stud spaces, the vapor barrier should be held in place by battens tacked or stapled to the frame around the opening as shown in figure 15–14.

15.62. Repair of Curtain Barriers.—Curtain types of insulation such as aluminum foil generally serve also as vapor barriers. Since they are easily torn, it is necessary to exercise care in repairing them or the damaged portion can easily be enlarged. To avoid enlarging the damage, the panel cover should be carefully cut out, with the cut-out kept as small as possible; otherwise, the keyhole saw usually used for this purpose may tear the foil beyond the damaged area, increasing the difficulty of repairing it. Because foil tears easily and asphalt paint does not adhere well to it, wood backup and hold-down strips are necessary to fix the patch firmly to the original curtain.

A single curtain of foil insulation can be repaired by cutting out the damaged cover, trimming the foil, and placing backup blocks

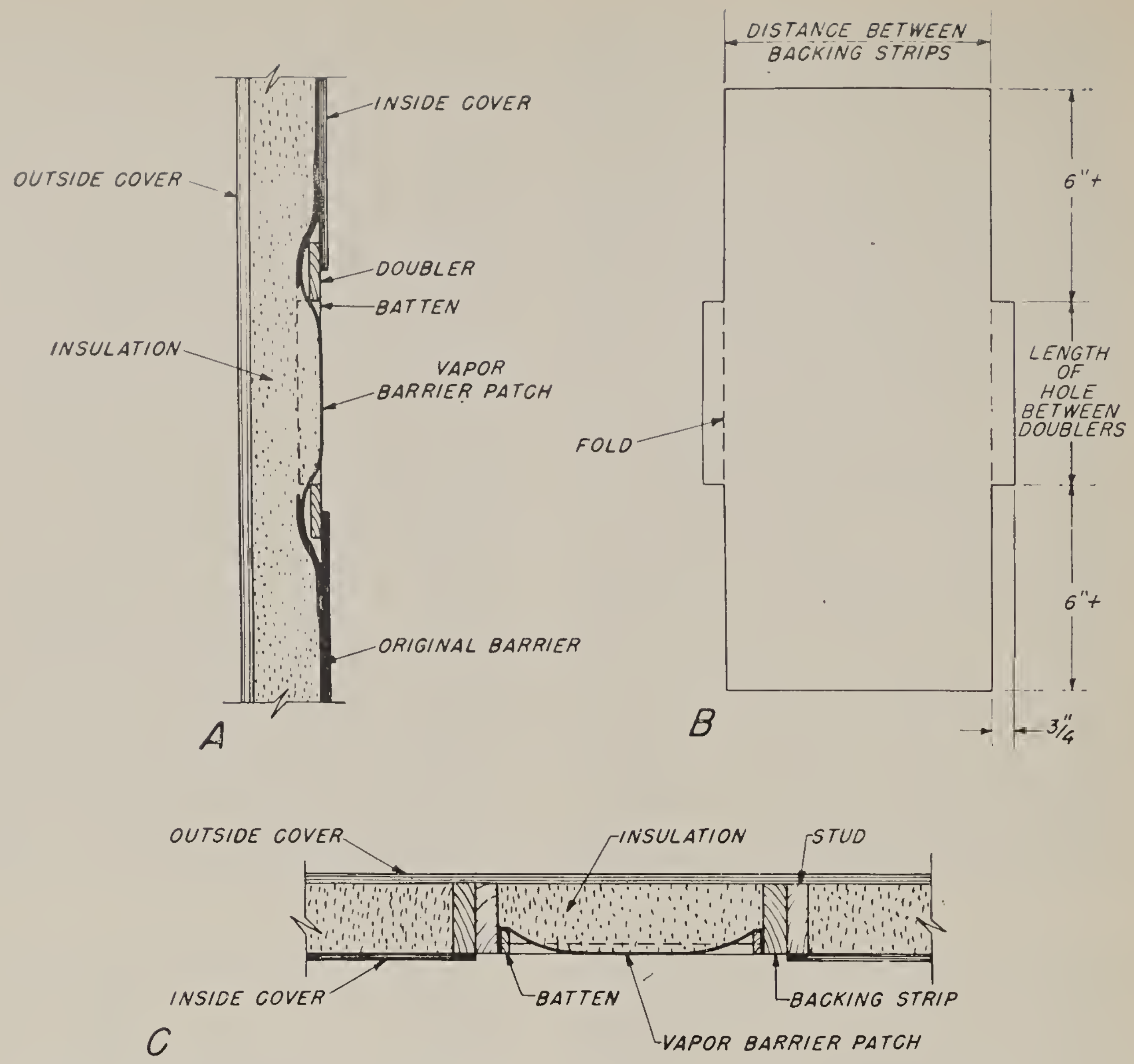

FIGURE 15–13.—Method of vapor barrier replacement when inside cover is removed from stud to stud but not for entire length of panel. *A*, vertical cross section; *B*, barrier patch cutout; *C*, horizontal cross section of panel.

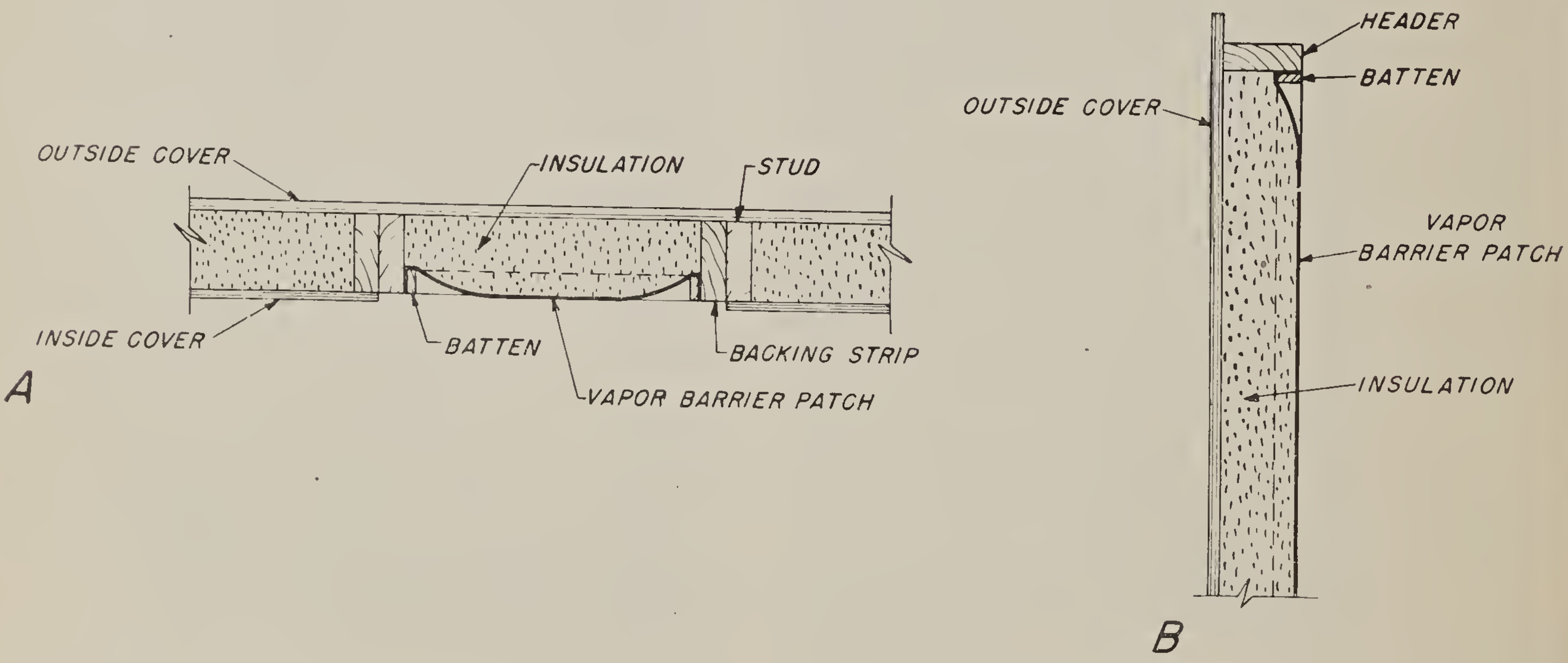

FIGURE 15–14.—Method of vapor barrier replacement when inside cover is removed from stud to stud entire length of panel. *A*, horizontal cross section; *B*, vertical cross section of panel.

of proper thickness underneath the perimeter of the damaged foil, nail gluing these strips to the undamaged cover of the panel. The strips at right angles to the studs should be at least 3 inches wide to provide an adequate lap between patch and curtain; those parallel to the studs should be 2 inches wide. The 3-inch strips are inserted so that they extend at least 2 inches under the original curtain.

The patch is cut large enough to allow at least a 3-inch overlap on all edges. Where this is not possible because of the closeness of a stud, a ¾-inch lap on one or both studs is provided. Asphalt paint is brushed on the original barrier edge and the backup strips, as well as on the studs, if the patch is to be lapped against them. It may be necessary to roll the patch partly for convenience in inserting it underneath the cover. Hold-down blocks of the same width as the backup strips, and the thickness of the air space between barrier and cover, are then nailed to the backup strips. The hold-down blocks also serve as backup strips for the cover patch.

The same system of backup and hold-down strips is used in repairing a double curtain of foil insulation, except that an additional set of strips, to serve as spacers between the two curtains, is installed.

15.63. Repair of Solid Fiberboard with Coated Barrier.—Solid fiberboard insulation is usually installed in panels so that an air space is between it and each cover. Where the damage to the barrier is limited to scuffing and the fiberboard remains relatively undamaged, a coating of the same barrier material as used on the fiberboard will usually suffice. If the fiberboard has been punctured, however, it will be necessary to cut out the damaged portion and install a plug-type patch, using backup strips as with foil types of insulation. The patch should be of the same type and thickness as the original fiberboard and should be well fitted; both it and the original insulation are nailed to the backup strips, spacing nails about 2 inches. An asphalt paint seal between the patch and the backup strips is recommended to give protection against passage of vapor through the cracks between the patch and the original fiberboard. The opening in the cover can then be repaired with a permanent patch.

GLOSSARY

Acetylated wood.—Wood whose chemical composition is altered by treatment with acetic anhydride and pyridine sufficiently to reduce greatly its tendency to swell and shrink.

Air-dried.—(See Seasoning.)

Alinement.—The course or location of elements of design or construction in relation to a determined line.

American lumber standards.—American lumber standards embody provisions for softwood lumber dealing with recognized classifications, nomenclature, basic grades, seasoning standards, sizes, uniform workings, description, measurement, tally, shipping provisions, grade marking, tally cards, and inspection of lumber. The primary purpose of these standards is to serve as a guide or basic examples in the preparation or revision of the grading rules of the various lumber manufacturers' associations; their use as a framework for such rules will eliminate differences often existing. A purchaser in order to buy in conformity with American lumber standards must make use of association rules that are in conformity with them, as the basic standards are not in themselves commercial rules.

Annual growth ring.—(See Ring, annual growth.)

Assembly time.—The interval of time between spreading of glue and application of full gluing pressure.

Closed assembly.—The practice of applying glue to surfaces that are immediately laid together for an interval of time before pressure is applied, so that they are not freely exposed to the air.

Open assembly.—The practice of applying glue to surfaces that are freely exposed to the air until pressure is applied.

Base line.—A definitely located arbitrary line for reference control purposes.

Bastard sawn.—Hardwood lumber in which the annual rings make angles of 30° to 60° with the surface of the piece.

Beam.—A structural member transversely supporting a load.

Beams and stringers.—Large pieces (nominal dimensions 5 by 8 inches and up) of rectangular cross section graded with respect to their strength in bending when loaded on the narrow face.

Birdseye.—A small central spot with the wood fibers arranged around it in the form of an ellipse so as to give the appearance of an eye.

Blemish.—Anything, not necessarily a defect, marring the appearance of wood.

Blue stain.—(See Stain, blue.)

Boards.—(See Lumber.)

Bow.—That distortion of a board in which the face is convex or concave longitudinally.

Boxed heart.—The term used when the pith falls entirely within the four faces anywhere in the length of a piece.

Brashness.—A condition of wood characterized by low resistance to shock and by an abrupt failure across the grain without splintering.

Bridging.—Small wood members that are inserted in a diagonal position between the floor joists acting both as tension and compression members for the purpose of bracing the joists and spreading the action of the effect of loads.

Broad-leaved trees.—(See Hardwoods.)

Brown stain.—(See Stain, brown.)

Building code.—A collection of legal requirements the purpose of which is to protect the safety, health, morals, and general welfare of those in and about buildings.

Burl.—A large wartlike excrescence on a tree trunk. It contains the dark piths of a large number of buds which rarely develop. The formation of a burl apparently results from an injury to the tree.

Cambium.—The layer of tissue just beneath the bark from which the new wood and bark cells of each year's growth develop.

Cell.—A general term for the minute units of wood structure. It includes fibers, vessel seg-

ments, and other elements of diverse structure and functions.

Cellulose.—The carbohydrate that is the principal constituent of wood and forms the framework of the cells.

Check.—A lengthwise separation of the wood, the greater part of which occurs across the rings of annual growth.

Chemical brown stain.—(See Stain, chemical brown.)

Close-grained wood.—(See Grain.)

Coarse-grained wood.—(See Grain.)

Collapse.—The flattening of single cells or rows of cells in heartwood during the drying or pressure treatment of wood, characterized externally by a caved-in or corrugated appearance.

Collar beam.—A tie connecting roof rafters at a level usually considerably above the top wall plate.

Column:

1. In architecture: A perpendicular supporting member, circular in section, usually consisting of a base, shaft, and capital.
2. In engineering: A structural compression member, usually vertical, supporting loads acting on or near and in the direction of its longitudinal axis. (Compare Pier.)

Compartment kiln.—(See Kiln.)

Compreg.—A stable form of resin-impregnated wood that has been highly compressed to increase its density and hardness.

Compression wood.—Abnormal wood that often forms on the lower side of branches and of leaning trunks of softwood trees. Compression wood is identified by its relatively wide annual rings, usually eccentric, and its relatively large amount of summer wood, usually more than 50 percent of the width of the annual rings in which it occurs. Compression wood shrinks excessively lengthwise as compared with normal wood.

Conifer.—(See Softwoods.)

Construction.—The materials and methods of fabricating the various elements of a structure or building.

Construction types:

Dry-wall construction.—A type of construction in which the interior wall finish is of a material other than plaster or material similar to it.

Prefabricated construction.—A type of construction so designed as to involve a minimum of assembly at the site, usually comprising a series of floor, wall, roof, or ceiling panels manufactured in a plant.

Stressed-cover construction. — Construction consisting of panels or sections with wood frameworks to which plywood or other sheet material is bonded with glue so that the covering carries a large part of the loads imposed.

Unit construction.—(See Unit construction.)

Wood-frame or frame construction.—A type of construction in which the structural parts are of wood or dependent upon a wood frame for support. In codes, if brick or other incombustible material is applied to exterior walls, the classification of this type of construction is usually unchanged.

Cornice.—A decorative element made up of molded members usually placed at or near the top of an exterior or interior wall.

Cover, coverage, covering.—Any material attached to a building framework to enclose the space within the framework.

Crook.—That distortion of a board in which the edge is convex or concave longitudinally.

Crossband.—To place the grain of layers of wood at right angles in order to minimize shrinking and swelling and consequent warping; also the layer of veneer at right angles to the face plies.

Cross break.—A separation of the wood cells across the grain. Such breaks may be due to internal strains resulting from unequal longitudinal shrinkage or to external forces.

Cross grain.—(See Grain.)

Cup.—The distortion of a board in which the face is convex or concave transversely.

Decay.—Disintegration of wood substance through the action of wood-destroying fungi.

Incipient decay.—The early stage of decay in which the disintegration has not proceeded far enough to soften or otherwise impair the hardness of the wood perceptibly.

Typical or advanced decay.—The stage of decay in which the disintegration is readily recognized because the wood has become punky, soft and spongy, stringy, pitted, or crumbly.

Defect.—Any irregularity occurring in or on wood that may lower its strength.

Density.—The mass of a body per unit volume. When expressed in the metric system, it is numerically equal to the specific gravity of the same substance.

Density rule.—Rules for estimating the density of wood based on percentage of summerwood and rate of growth. The rules at present apply only to southern yellow pine and Douglas-fir and differ slightly.

Diagonal grain.—(See Grain.)

Diamond.—A distortion in drying that causes a piece of wood originally rectangular in cross section to become diamond-shaped.

Diffuse-porous woods.—Hardwoods in which the pores are practically uniform in size throughout each annual ring, or decrease slightly toward the outer border of the ring.

Dimension.—(See Lumber.)

Dimension stock.—Squares or flat stock usually in pieces under the minimum sizes admitted in standard lumber grades, rough or dressed, green or dry, cut to the approximate dimensions required for the various products of woodworking factories.

Dote.—"Dote," "doze," and "rot" are synonymous with "decay," and are any form of decay which may be evident as either a discoloration or a softening of the wood.

Dry rot.—A term loosely applied to many types of decay but especially to that which, when in an advanced stage, permits the wood to be easily crushed to a dry powder. The term is actually a misnomer for any decay, since all fungi require considerable moisture for growth.

Durability.—A general term for permanence or lastingness. Frequently used to refer to the degree of resistance of a species or of an individual piece of wood to attack by wood-destroying fungi under conditions that favor such attack. In this connection the term "resistance to decay" is more specific.

Edge grain.—(See Grain.)

Empty-cell process.—Any process for impregnating wood with preservatives of chemicals in which air is imprisoned in the wood under the pressure of the entering preservative and then expands, when the pressure is released, to drive out part of the injected preservative.

Encased knot.—(See Knot.)

Extractives.—Substances in wood, not an integral part of the cellular structure, that can be dissolved out with hot or cold water, ether, benzene, or other relatively inert solvents.

Equilibrium moisture content.—The moisture content at which wood neither gains nor loses moisture when surrounded by air at a given relative humidity and temperature.

Factory and shop lumber.—(See Lumber.)

Fiber.—A wood fiber is a comparatively long (one-twenty-fifth or less to one-third inch), narrow, tapering cell closed at both ends.

Fiber-saturation point.—The stage in the drying or in the wetting of wood at which the cell walls are saturated and the cell cavities are free from water. Usually taken as approximately 30 percent moisture content.

Figure.—The pattern produced in a wood surface by irregular coloration and by annual growth rings, rays, knots, and such deviations from regular grain as interlocked and wavy grain.

Fire-retardant chemical.—A chemical or preparation of chemicals used to reduce flammability or to retard spread of flame.

Fire stop.—A solid, tight closure of a concealed space, placed to prevent the spread of fire and smoke through such a space.

Flakes.—(See Rays, wood.)

Flashing.—Sheet metal or other material used in roof and wall construction to protect a building from seepage of water.

Flat grain.—(See Grain.)

Footing.—The spreading course or courses at the base or bottom of a foundation wall, pier, or column.

Foundation.—The supporting portion of a structure below the first-floor construction, or grade, including the footings.

Full-cell process.—Any process for impregnating wood with preservatives or chemicals in which a vacuum is drawn to remove air from the wood before admitting the preservative.

Furring.—Strips of wood or metal applied to a wall or other surface to even it, to form an air space, or to give an appearance of greater thickness.

Gable.—That portion of a wall contained between the slopes of a double-sloped roof or that portion contained between the slope of a single-sloped roof and a line projected horizontally through the lowest elevation of the roof construction.

Girder.—A large or principal beam used to support concentrated loads at isolated points along its length.

Grade.—The designation of the quality of a manufactured piece of wood.

Grain.—The direction, size, arrangement, appearance, or quality of the fibers in wood.

Close-grained wood.—Wood wit hnarrow and inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine textured" is more often used.

Coarse-grained wood.—Wood with wide and conspicuous annual rings; that is, rings in which there is considerable difference between spring wood and summer wood. The term is sometimes used to designate wood with large pores, such as oak, ash, chestnut, and walnut, but in this sense the term "coarse textured" is more often used.

Cross grain.—Grain not parallel with the axis of a piece. It may be either diagonal or spiral grain or a combination of the two.

Diagonal grain—Annual rings at an angle with the axis of a piece as a result of sawing at an angle with the bark of the tree.

Edge grain.—Edge-grain lumber has been sawed parallel with the pith of the log and approximately at right angles to the growth rings; that is, the rings form an angle of 45° or more with the surface of the piece.

Flat grain.—Flat-grain lumber has been sawed parallel with the pith of the log and approximately tangent to the growth rings; that is, the rings form an angle of less than 45° with the surface of the piece.

Interlocked-grained wood.—Wood in which the fibers are inclined in one direction in a number of rings of annual growth, then gradually reverse and are inclined in an opposite direction in succeeding growth rings, then reverse again.

Open-grained wood.—Common classification of painters for woods with large pores, such as oak, ash, chestnut ,and walnut. Also known as "coarse-textured."

Plain-sawed.—Another term for flat grain.

Quarter-sawed. — Another term for edge grain.

Spiral grain.—A type of growth in which the fibers take a spiral course about the bole of a tree instead of the normal vertical course. The spiral may extend right-handed or left-handed around the tree trunk.

Vertical grain.—Another term for edge grain.

Wavy-grain wood.—Wood in which the fibers collectively take the form of waves or undulations.

Green.—Unseasoned, wet.

Growth ring.—(See Ring, annual growth.)

Hardwoods.—The botanical group of trees that are broadleaved. The term has no reference to the actual hardness of the wood. Angiosperms is the botanical name for hardwoods.

Header.—A beam placed perpendicular to joists and into which joists are framed in framing for a chimney, stairway, or other opening. (Compare Trimmer.)

Heart, Heartwood.—The wood, extending from the pith to the sapwood, the cells of which no longer participate in the life processes of the tree. Heartwood may be infiltrated with gums, resins, and other materials which usually make it darker and more decay-resistant than sapwood.

Honeycomb.—Checks, often not visible at the surface, that occur in the interior of a piece, usually along the wood rays.

Imperfect manufacture.—Includes all defects or blemishes which are produced in manufacturing, such as chipped grain, loosened grain, raised grain, torn grain, skips in dressing, hit and miss, variation in sawing, miscut lumber, machine burn, machine gouge, mismatching, and insufficient tongue or groove.

Impreg.—Wood the cell-wall structure of which is impregnated with synthetic resin, usually phenolic, to reduce swelling and shrinking and thus stabilize its dimensions.

Interlocked grained wood.—(See Grain.)

Joist.—One of a series of parallel beams used to support floor and ceiling loads, and supported in turn by larger beams, girders, or bearing walls.

Joist and plank.—Pieces (nominal dimensions 2 to 4 inches in thickness by 4 inches and wider) of rectangular cross section graded with respect to their strength in bending when loaded either on the narrow face as joist or on the wide face as plank.

Kiln.—A heated chamber for drying lumber.

Compartment kiln.—A dry kiln designed to keep the same temperature and relative humidity throughout at any given time. In it the entire charge of lumber is dried as a unit, under drying conditions that increase in severity as the wood dries.

Progressive kiln.—A dry kiln designed to provide drying conditions that increase in severity from entrance to exit. In it the unit charge is only a part of the total charge of lumber; a unit charge of perhaps four truck loads is moved through the kiln in a chain of several such units, from day to day, with one unit leaving and another entering at a time.

Kiln brown stain.—(See Stain, chemical brown.)

Kiln dried.—(See Seasoning.)

Knot.—That portion of a branch or limb that has become incorporated in the body of a tree.

Decayed knot.—A knot which, due to advanced decay, is not so hard as the surrounding wood.

Encased knot.—A knot whose rings of annual growth are not intergrown with those of the surrounding wood.

Intergrown knot.—A knot whose rings of annual growth are completely intergrown with those of the surrounding wood.

Round knot.—A knot whose sawn section is oval or circular.

Sound knot.—A knot which is solid across its face and which is as hard as the surrounding wood.

Spike knot.—A knot sawn in a lengthwise direction.

Laminated wood.—A piece of wood built up of plies or laminations that have been joined either with glue or with mechanical fastenings. The term is most frequently applied where the plies are too thick to be classified as veneer and when the grain of all plies is parallel.

Lath.—A building material of wood, metal, gypsum, or insulation board, that is fastened to the frame of a building to act as a plaster base.

Lignin.—A principal constituent of wood, second in quality to cellulose. It incrusts the cell walls and cements the cells together.

Lintel.—A horizontal structural member which supports the load over an opening such as a door or window.

Loads:

Dead load.—The weight of all permanent stationary construction included in a building.

Live load.—The total of all moving and variable loads that may be placed upon a building.

Lumber.—The product of the saw and planing mill not further manufactured than by sawing, resawing, and passing lengthwise through a standard planing machine, crosscut to length and worked.

Dressed size.—The dimensions of lumber after shrinking from the green dimension and planing; usually 3/8 inch less than the nominal or rough size; for example, a 2 by 4 stud actually measures $1\frac{5}{8}$ by $3\frac{5}{8}$ inches. (See Lumber, Nominal size.)

Factory and shop lumber.—Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified, or a given minimum, size and quality.

Matched lumber.—Lumber that is edge dressed and shaped to make a close tongue-and-groove joint at the edges or ends when laid edge to edge or end to end.

Nominal size.—As applied to timber or lumber, the rough-sawn commercial size by which it is known and sold in the market. (See Lumber, Dressed size.)

Plank.—A broad board, usually more than 1 inch thick, laid with its wide dimension horizontal and used as a bearing surface.

Rough lumber.—Lumber as it comes from the saw.

Shiplapped lumber.—Lumber that is edge-dressed to make a close rabbetted or lapped joint.

Surfaced lumber.—Lumber that is dressed by running it through a planer.

Yard lumber.—Lumber that is less than 5 inches in thickness and is intended for general building purposes.

Boards.—Yard lumber less than 2 inches thick, 8 inches or more in width.

Dimension.—All yard lumber except boards, strips, and timbers; that is, yard lumber 2

inches and less than 5 inches thick, and of any width.

Strips.—Yard lumber less than 2 inches thick and less than 8 inches wide.

Millwork.—Generally all building materials made of finished wood and manufactured in millwork plants and planing mills are included under the term "millwork." It includes such items as inside and outside doors, window and door frames, blinds, porch work, mantels, panel work, stairways, moldings, and interior trim. It does not include flooring, ceiling, or siding.

Modular panel.—Any panel of standard dimensions, particularly width, multiples of which are taken as governing wall, floor, ceiling, and roof dimensions.

Moisture content of wood.—Weight of the water contained in the wood usually expressed in percentage of the weight of the oven-dry wood.

Moisture gradient.—A condition of graduated moisture content between the successive layers of a material, such as wood, due to the losing or absorbing of moisture. During seasoning the gradations are between the moisture content of the relatively dry surface layers and the wet layers at the center of the piece.

Mullion.—A slender bar or pier forming a division between panels or units of windows, screens, or similar frames.

Open-grained wood.—(See Grain.)

Panel.—In prefabricated housing, a factory-made wall, floor, ceiling, or roof construction that includes framework and cover, with or without insulation, electrical wiring, and other equipment. Note: Sheets of plywood and other building materials are often called panels.

Papreg.—Any of various paper products made by impregnating sheets of specially manufactured high-strength paper with synthetic resin, usually phenolic, and laminating the sheets to form a dense moisture-resistant product.

Partition.—A wall that subdivides spaces within any story of a building.

Partition types:

Bearing partition.—A partition which supports any vertical load in addition to its own weight.

Fire partition.—A partition designed to restrict the spread of fire, or to provide an area of refuge.

Nonbearing partition.—A partition extending from floor to ceiling which supports no load other than its own weight.

Peck.—Pockets or areas of disintegrated wood caused by advanced stages of localized decay in the living tree. It is usually associated with cypress and incense cedar. There is no further development of peck once the lumber is seasoned.

Pier.—A column of masonry, usually rectangular in horizontal cross section, used to support other structural members.

Pitch pocket.—An opening extending parallel to the annual rings of growth usually containing, or which has contained, pitch, either solid or liquid.

Pith.—The small soft core occurring in the structural center of a log.

Plain-sawed.—(See Grain.)

Planing mill products.—Products worked to pattern, such as flooring, ceiling, and siding.

Plate:

1. A horizontal structural member placed on a wall or supported on posts, studs, or corbels to carry the trusses of a roof or to carry the rafters directly.
2. A shoe or base member, as of a partition or other frame.
3. A small, relatively flat member placed on or in a wall to support girders, rafters, and other framing.
4. A nonstructural protective unit, such as a push-plate or kick-plate.

Plywood.—A piece of wood made of three or more layers of veneer joined with glue and usually laid with the grain of adjoining plies at right angles. Almost always an odd number of plies are used to secure balanced construction.

Pocket rot.—Advanced decay which appears in the form of a hole, pocket, or area of soft rot usually surrounded by apparently sound wood.

Pore.—(See Vessel.)

Posts and timbers.—Pieces of square or approximately square cross section, 4 by 4 inches or larger in nominal dimensions graded primarily for use as posts or columns but adapted to miscellaneous uses in which

strength in bending is not especially important.

Preservative.—Any substance that, for a reasonable length of time, will prevent the action of wood-destroying fungi, borers of various kinds, and similar destructive life when the wood has been properly coated or impregnated with it.

Progressive kiln.—(See Kiln.)

Purlin.—A horizontal member usually laid at right angles to main rafters or trusses of a roof to support elements of the roof framing.

Quarter-sawed.—(See Grain.)

Rabbet.—A rectangular longitudinal groove cut in the corner of a board or other piece of material.

Radial.—Coincident with a radius from the axis of the tree or log to the circumference.

Rafter.—One of a series of structural members of a roof designed to support roof loads. The rafters of a flat roof are sometimes called roof joists.

Rafter types:

Hip rafter.—A rafter which forms the intersection of an external roof angle.

Jack rafter.—A rafter which spans the distance from a wall plate to a hip or from a valley to a ridge.

Valley rafter.—A rafter which forms the intersection of an internal roof angle.

Rate of growth.—The rate at which a tree has laid on wood, measured radially in the trunk or in lumber cut from the trunk. The unit of measure in use is number of annual growth rings per inch.

Rays, wood.—Strips of cells extending radially within a tree and varying in height from a few cells in some species to 4 inches or more in oak. The rays serve primarily to store food and transport it horizontally in the tree.

Ring, annual growth.—The growth layer put on in a single growth year.

Ring-porous woods.—A group of hardwoods in which the pores are comparatively large at the beginning of each annual ring and decrease in size more or less abruptly toward the outer portion of the ring, thus forming a distinct inner zone of pores known as the springwood and the outer zone with smaller pores known as the summerwood.

Roof.—The entire construction used to close in the top of a building.

Roof hip.—The sloping line at the junction of two roof surfaces where an external angle greater than 180 degrees is formed.

Roof ridge.—The horizontal line at the junction of the top edges of two roof surfaces where an external angle greater than 180 degrees is formed.

Roof types:

Flat roof.—A rof which is flat or one which is pitched only enough to provide for drainage. (Compare Roof types; Pitched roof.)

Gabled roof.—A ridge roof which terminates in a gable.

Hip (or hipped) roof.—

1. In general, a roof which has one or more hips.
2. A roof which has four sloping sides that meet at four hips, or at four hips and a ridge.

Pitched roof.—A roof which has one or more sloping surfaces pitched at angles greater than necessary for drainage. (Compare Roof types. Flat roof.)

Ridge roof.—A roof which has one or more ridges.

Roofing.—The materials applied to the structural parts of a roof to make it watertight.

Rot.—(See Decay.)

Rotary-cut veneer.—(See Veneer.)

Sap.—All the fluids in a tree, special secretions and excretions, such as gum, excepted.

Sapwood.—The layers of wood next to the bark, usually lighter in color than the heartwood, one-half inch to 3 or more inches wide that are actively involved in the life processes of the tree. Under most conditions sapwood is more susceptible to decay than heartwood; as a rule, it is more permeable to liquids than heartwood. Sapwood is not essentially weaker or stronger than heartwood of the same species.

Sawed veneer.—(See Veneer.)

Seasoning.—Removing moisture from green wood in order to improve its serviceability.

Air-dried or air seasoned.—Dried by exposure to the air, usually in a yard, without artificial heat.

Kiln dried.—Dried in a kiln with the use of artificial heat.

Second growth.—Timber that has grown after the removal by any means of all or a large portion of the previous stand.

Section.—Any panelized construction of variable dimensions, particularly width, used in walls, floors, ceilings, or roofs.

Room-length wall section.—A panelized construction whose width is the full length of one wall of a room.

Shake.—A separation along the grain, the greater part of which occurs between the rings of annual growth.

Sheathing.—The structural covering, usually of boards or wallboards, placed over exterior studding or rafters of a structure.

Sheathing paper.—A building material used in wall and roof construction as a protection against the passage of air and sometimes moisture.

Shop lumber.—(See Lumber.)

Sill:

1. The lowest member of the frame of a structure, usually horizontal, resting on the foundation and supporting the uprights of the frame.
2. That member forming the lower side of an opening, as door sill, window sill, etc.

Sliced veneer.—(See Veneer.)

Softwoods.—The botanical group of trees that have needle or scalelike leaves and are evergreen for the most part, cypress, larch, and tamarack being exceptions. The term has no reference to the actual hardness of the wood. Softwoods are often referred to as conifers, and botanically they are called gymnosperms.

Span.—The distance between structural supports such as walls, columns, piers, beams, girders, and trusses.

Specific gravity.—The ratio of the weight of a body to the weight of an equal volume of water at some standard temperature.

Spiral grain.—(See Grain.)

Split.—A lengthwise separation of the wood, due to the tearing apart of the wood cells.

Springwood.—The portion of the annual growth ring that is formed during the early part of the season's growth. It is usually less dense and weaker mechanically than summerwood.

Stain, blue.—A bluish or grayish discoloration of the sapwood caused by the growth of certain moldlike fungi on the surface and in the interior of the piece; made possible by the same conditions that favor the growth of other fungi.

Stain, brown.—A rich brown to deep chocolate-brown discoloration of the sapwood of some pines caused by a fungus that acts similarly to the blue-stain fungus.

Stain, chemical brown.—A chemical discoloration of wood, which sometimes occurs during the air drying or the kiln drying of several species, apparently caused by the oxidation of extractives.

Stain, sap.—(See Stain, blue.)

Staybwood.—Wood heated in the absence of air, as in a molten bath, to temperatures just below the charring point for periods of time necessary to reduce substantially its tendency to swell and shrink.

Staypak.—Wood that is compressed in its natural state (that is without resin or other chemical treatment) under conditions of moisture and pressure that practically eliminate springback, or recovery from compression.

Strength.—The term in its broader sense embraces collectively all the properties of wood which enable it to resist different forces or loads. In its more restricted sense, strength may apply to any one of the mechanical properties, in which event the name of the property under consideration should be stated, thus strength in compression parallel to the grain, strength in bending, hardness, etc.

Stressed-cover construction. — Construction consisting of panels or sections with wood frameworks to which plywood or other sheet material is bonded with glue so that the covering carries a large part of the loads imposed.

Strips.—(See Lumber.)

Structural timber.—Pieces of wood of relatively large size in which strength is the controlling element in their selection and use. Trestle timbers (stringers, caps, posts, sills, bracing, bridge ties, guard rails); car timbers (car framing, including upper framing, car sills); framing for buildings (posts, sills, girders, framing joists); ship timbers (ship timbers, ship decking); and cross arms for poles are examples of structural timbers.

Stud.—One of a series of slender wood struc-

tural members used as supporting elements in walls and partitions. (Plural: studs or studding.)

Summerwood.—The portion of the annual growth ring that is formed during the latter part of the yearly growth period. It is usually more dense and stronger mechanically than springwood.

Tangential.—Strictly, coincident with a tangent at the circumference of a tree or log, or parallel to such a tangent. In practice, however, it often means roughly coincident with a growth ring.

Termite shield.—A shield, usually of sheet metal, placed in or on a foundation wall or other mass of masonry or around pipes to prevent the passage of termites.

Texture.—A term often used interchangeably with grain. It refers to the finer structure of the wood (see Grain) rather than the annual rings.

Thermoplastic glues.—Glues that are cured with heat and soften when subsequently subjected to high temperatures.

Thermosetting glues.—Glues that are cured with heat but do not soften when subsequently subjected to high temperatures.

Thermostat.—An instrument that controls automatically the operation of heating or cooling devices by responding to changes in temperature.

Timber, standing.—Timber still on the stump.

Timbers.—Lumber 5 inches or larger in least dimension.

Tracheid.—The elongated cells that constitute the greater part of the structure of the softwoods (frequently referred to as fibers). Also a portion of some hardwoods.

Trim.—The finish materials in a building, such as moldings applied around openings (window trim, door trim) or at the floor and ceiling of rooms (baseboard, cornice, picture molding).

Trimmer.—A beam or joist into which a header is framed in framing for a chimney, stairway, or other opening. (Compare Header.)

Twist.—A distortion caused by the turning or winding of the edges of a board so that the four corners of any face are no longer in the same plane.

Unit construction.—Construction which includes two or more preassembled walls, together with floor and ceiling construction, for shipment to the building site.

Veneer.—Thin sheets of wood.

Rotary-cut veneer.—Veneer cut in a continuous strip by rotating a log against the edge of a knife in a lathe.

Sawed veneer.—Veneer produced by sawing.

Sliced veneer.—Veneer that is sliced off by moving a log,bolt, or flitch against a large knife.

Ventilation.—The process of supplying and removing air by natural or mechanical means to or from any space. (Such air may or may not have been conditioned.)

Vertical grain.—(See Grain.)

Vessels.—Wood cells of comparatively large diameter which have open ends and are set one above the other forming continuous tubes. The openings of the vessels on the surface of a piece of wood are usually referred to as pores.

Virgin growth.—The original growth of mature trees.

Walls:

Bearing wall.—A wall which supports any vertical load in addition to its own weight.

Curtain wall.—A nonbearing wall between columns or piers which is not supported by girders or beams.

Exterior wall.—Any outside wall or vertical enclosure of a building other than a party or common wall.

Foundation wall.—Any bearing wall or pier below the first-floor construction.

Nonbearing wall.—A wall which supports no vertical load other than its own weight.

Wallboard.—Wood pulp, gypsum, or similar materials made into large rigid sheets that may be fastened to the frame of a building to provide a surface finish.

Wane.—Bark, or lack of wood or bark, from any cause, on edge or corner of a piece.

Warp.—Any variation from a true or plane surface. Warp includes bow, crook, cup, and twist, or any combination thereof.

Wavy-grained wood.—(See Grain.)

Weathering.—The mechanical or chemical disintegration and discoloration of the surface of wood that is caused by exposure to light, the action of dust and sand carried by winds, and the alternate shrinking and swelling of the surface fibers that come with the con-

tinual variation in moisture content brought by changes in the weather. Weathering does not include decay.

Wood preservative.—(See Preservative.)

Workability.—The degree of ease and smoothness of cut obtainable with hand or machine tools.

Working life.—The period of time, after preparation for use, during which a glue remains at a consistency suitable for application.

Working of wood.—Change in the dimensions of a piece of wood with change in moisture content.

Yard brown stain.—(See Stain, chemical brown.)

Yard lumber.—(See Lumber.)

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